IMPACT OF TRUCK PLATOONING ON TEXAS BRIDGES

A Thesis

by

NANDHU PILLAY THULASEEDHARAN

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Chair of Committee,	Matthew Yarnold
Committee Members,	Mohammed Haque
	Petros Sideris
Head of Department,	Robin Autenrieth

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ABSTRACT

United States trucking industry has an annual revenue output of $725 billion and is expected to grow by over 40 percent by 2045. The biggest challenges faced by the industry is the ever-increasing oil prices and the shortage of drivers to meet the growing demands. Truck platooning provides an efficient solution for both the challenges, which can be incorporated by equipping the existing inventory with modern sensors and systems. Platooning of trucks is the process by which two or more trucks move together along highways, maintaining a constant close space between them also allowing for significant fuel savings.

The scope of this study is to research the potential impacts of truck platoons on the Texas bridge inventory. Bridges are one of the major elements of the highway infrastructure. Texas has the largest bridge inventory in the USA with over 55,000 bridges (more than 40 percentage older than 40 years). Due to the large inventory under consideration, a subset of bridges most likely support future truck platoons was selected (6,550 bridges). For each of these structures estimated truck platoon load ratings were calculated according to the original design methodology (allowable stress, load factor, or load and resistance factor) using NBI data elements along with assumptions from prior studies. The obtained load ratings from the older structures were then standardized to the load and resistance factor rating method. Then the bridges were prioritized considering the effects of the bridge condition. This identified the structures that require the earliest attention. In total, six different trucks at four different spacings under two- and three-truck platoons were analyzed as a part of the research. In addition, a cost benefit analysis is also performed with respect to truck platoons and bridges for better understanding of the benefits. Overall conclusions were drawn regarding the sensitivity of the original design methodology, bridge span length, truck type, truck spacing and number of trucks within a platoon on the bridge prioritization. In addition, a secondary benefit of the study is that a framework is presented for other bridge owners to prioritize their bridges that may be subjected to truck platoon or other heavy vehicle loading.

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NOMENCLATURE

AASHTO	American Association of State Highway and Transportation Officials
ACC	Adaptive Cruise Control
ADT	Average Daily Traffic
ADTT	Average Daily Truck Traffic
AISC	American Institute of Steel Construction
ASD	Allowable Stress Design
ASR	Allowable Stress Rating
CACC	Cooperative Adaptive Cruise Control
EOR	Equivalent Operator Rating
FCAM	Forward Collison Avoidance Mitigation Technology
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
GVW	Gross Vehicle Weight
IR	Inventory Rating
LFD	Load Factor Design
LFR	Load Factor Rating
LLRF	Live Load Reduction Factor
LRFD	Load and Resistance Factor Design

LRFR	Load and Resistance Factor Rating
MBE	Manual for Bridge Evaluation
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
OR	Operator Rating
RF	Rating Factor
SAE	Society of Automotive Engineers
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation

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1. INTRODUCTION AND MOTIVATION

Trucks are key elements in fostering the economic growth of the United States. Though trucks form just 4% of the vehicles on the road, they enable the movement of nearly 70% of the nation's freight. This accounts for more than $725 billion in revenue on an annual basis with fuel representing 38% of the operational costs, consuming 20% of U.S. transportation fuel (Windover et al., 2018). In addition, the trucking industry is expected to grow by over 40 percent by 2045 in order to cater for the growing U.S. economy.

Incorporating automation technologies into the trucking industry is a process that has begun from the early 1990's. While automation in vehicle-based industries have been around for a while, trucking industry has been focused on immediate automation for the following reasons-

1) Human drivers require mandatory rest breaks to avoid fatigue. This inevitable inefficiency makes the freight traffic slower and has a significant role in raising the overall costs involved. The ability of autonomous trucks to operate round the clock can almost double the performance of trucking industry. While for a self-driving car, the user will be always riding in the vehicle and hence there may not be a performance improvement from human point of view. It is estimated that an annual saving of $97 billion can be achieved, as a result of productivity gain and labor savings due to automation.

2) Due to the poor working conditions and lower pay involved, the number of new long-haul truck drivers have fallen over the years. It is estimated that there will be a shortage of over two hundred thousand drivers by the end of the decade.
3) An important factor behind push for automation, is the significant reduction in accidents involving trucks with the incorporation of automation technologies. In 2017, 13% of annual roadway fatalities involved large trucks and 82% of victims in fatal large truck crashes were road users who were not an occupant of the truck(s) involved (Perry et al., 2018). Most of these accidents were caused by either small vehicular cut-ins or due to a tired director truck driver. Studies has shown that addition of FCAM technology in trucks have reduced the occurrence of rear end collisions and un-safe following by over 70 and 60 % respectively. It is estimated that there will be an annual accidental savings of $36 billion upon implementation of automation technologies in trucks.
4) Various automation technologies like cruise control and sensor based braking technologies help in reducing the fuel consumption of trucks significantly along long-haul highway routes. It is estimated that, the trucking industry can save $40 billion annually, if the existing automation techniques are incorporated in all trucks (Chottani et al.,2018).

1.1. Levels of Automation

The Automation Scale used by the Society of Automotive Engineers is the most commonly used method to define the level of automation of a vehicular system. Vehicle automation is expressed in scale of 0 to 5, where level zero means no automation and level

5 means the vehicle can drive without any human intervention. Level 1 to 4 represents increasing level of automation. Level 1 and 2 have added features to exiting vehicles, which reduce the strain of drivers and provides improved safety of vehicles. Level 3 and 4 systems are able to drive automatically under controlled test setups and specific highway routes. Level 5 systems can operate under any physical scenario without any human intervention. Level 4 and 5 trucking technologies will depend on technologies like lidar, cameras and motion sensors to collect data about the road in which they are traveling. They data is fed into a computer system, which uses the data to create a 3-dimensional map of truck's surrounding. This map along with available GPS and GIS analysis data helps in formulating an accurate algorithm for the movement of vehicles (Perry et al., 2018). Figure 1 is a visual representation of the various levels of automation.

1.2. Platooning

Truck Platooning is a narrow subset within connected and automated vehicles, which has recently gained much attraction among researchers and trucking industry due to its various advantages and ability to be launched on a commercial scale in the immediate future. "Platooning" can be defined as two or more vehicles following each other in close proximity connected virtually for the purpose of reduced aerodynamic drag and increased roadway usage. Even though Platooning is adaptable to all vehicle classes and types, research on platooning of trucks has been a forerunner due to its various benefits. Primary benefit of truck platooning is its reduced fuel consumption and in turn the consequent reduction in associated greenhouse gas (GHG) emissions. Figure 3 is a visual representation of the reduction in air drag due to implementation of platoons, which helps in reducing the fuel consumption.

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 1: Levels of automation (reprinted from S.A.E. "J3016.", 2014)

Experimental studies conducted on truck platooning have used a combination of GPS, sensors and Vehicle-to-Vehicle (V2V) communication systems to facilitate the trucks to follow closely by linking their acceleration and braking systems. Current studies involve a lead truck driven manually and the trailing trucks following through wireless information from the leading truck, especially in acceleration and braking maneuvers. Inter-vehicular connections help in significantly reducing the possibility of rear end collisions as well as reducing the overall stopping distance of the platoon. Fig. 2 show the benefits of truck platoon in terms of reduced air drag, reduced braking distance and enhanced safety. As shown in the figure, the linked braking of the platoon system helps in significantly reducing the braking distance of following trucks in platoon, when compared to trucks not in platoon (Kuhn et al., 2017), (Windover et al., 2018).

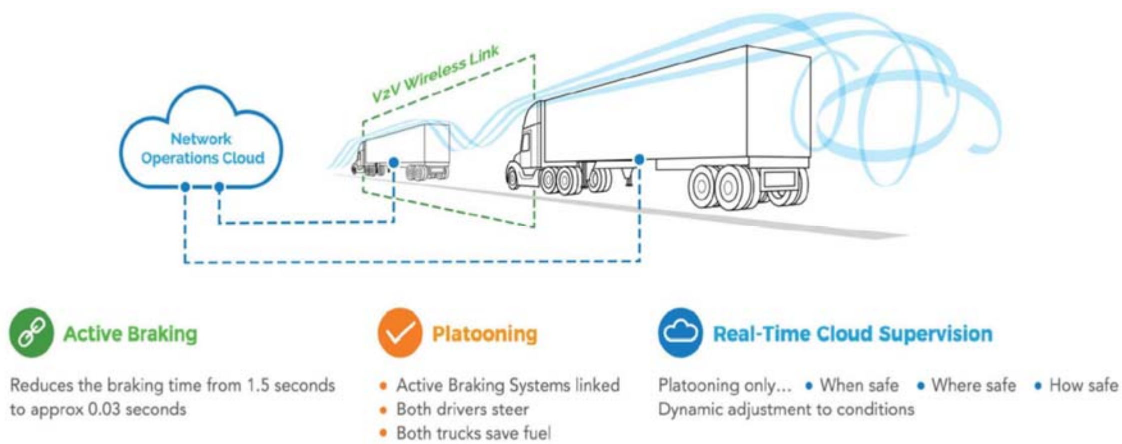

Figure 2: Figure showing, the reduced air drags and benefits of trucks in a platoon (Peloton, 2020)

1.2.1. Benefits

For a heavy truck, more than 50 % of the fuel consumption is spent on overcoming the aerodynamic drag of the truck. When the spacing between adjacent trucks is reduced, it helps in lowering the drag effect of the trailing trucks, in turn reducing the fuel consumption. McAuliffe (2018) did field experimentation of 2 and 3 truck 65-kip platoons with and without trailer attachments. Trailing trucks showed a maximum fuel saving of 17 % with a total effective saving of 13 % for the platoon system when the truck to truck spacing was 12 feet. The total savings reduced to below 6 % for spacings above 100 feet.

Given the fact that, one gallon of fuel can produce up to 20 lb. of carbon dioxide, platooning can help in reducing the emission of greenhouse gases significantly. In addition, the reduction in spacing between the trucks, helps in reducing the congestion levels along the Inter-State highway systems and helps in improving the overall highway capacity. Platooning also brings along with it, various safety features associated with vehicular automation, significantly reducing the chances of rear end collisions.

Due to its lucrative advantages a number of U.S. states have developed or are developing regulations that will allow platoons to operate within their state highways. The biggest deadlock with respect to most state legislatures, is the modification of the rules stating minimum allowable spacing between trucks along highways.

1.3. Need for the study

The concept of truck platooning brings along with it challenges for the highway infrastructure it will be plying on. Bridges are an integral part of the road inventory, as often without them, no road route will be complete. While in general, the plying of truck platoons, may not bring in design challenges with respect to highway pavement alignment or construction, as the overall dimensions and qualities of a single truck remains a constant, it can be of significant impact to highway infrastructures particularly bridges, due to the increase in live loads acting on a bridge well beyond the demands due to the presence of a platoon. Texas, due to its large size and geography, has an inventory with nearly 54,000 bridges (more than the combined inventories of 17 smaller states in USA). Hence the success and effectiveness of truck platooning in Texas depends a lot on the ability of its bridge inventory to resist the additional effects due to the platoon trucks.

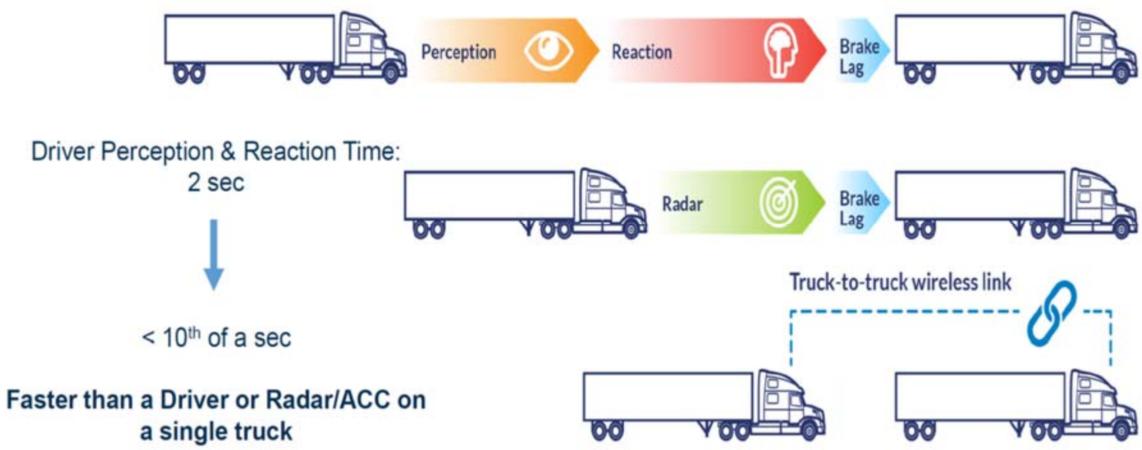

Figure 3: Truck to Truck minimum following distance needed for normal trucks and trucks in a platoon (Peloton,2020)

1.4. Objective

The objective of the research is to conduct a comprehensive study on the potential impacts truck platooning may have on the Texas bridge inventory. The thesis begins with an extensive review of the literature to obtain knowledge about similar studies. This step also involves the study of standard bridge plans from the Texas Department of Transportation (TxDOT) as well as National Cooperative Highway Research Program (NCHRP) load rating studies to obtain initial inventory rating values to be used later in the study. Next, a selection of the National Bridge Inventory (NBI) data elements (appraisal rating, maximum span length, year built / rehabilitated, and structure type) are used to calculate the approximate load ratings and relative priority index of each structure under different truck platooning configurations. The results are then combined together to formulate the impact of truck platooning on existing bridges as well as future bridge designs.

2. BACKGROUND AND LITERATURE REVIEW

All Truck Platooning systems require some basic hardware and electronic systems to run effectively. Current experimental studies based on platooning have been using technologies like millimeter wave /infrared laser radars in order to detect objects in front and around the vehicular system. Cameras were used to read highway signs and road markings and Dedicated Short Range Communication (DSRC) radios were used to communicate between trucks in platoon as well as the central control station. Trucks also included a digital truck control software to automatically adjust truck spacing and speeds. Some of the technologies to be used in truck platooning systems are already commercially available and have been used in some of the newer trucks manufactured. Presently about 20% of new trucks manufactured have some form of platooning technology incorporated in them, making future full-scale upgrades easier and cheaper.

Truck platooning levels can be described according to SAE automation levels as follows. Level 1 (L1) platooning is mainly aimed at formulating a system consisting of a completely human driven lead truck and 1 or 2 follower trucks connected by FCAM or CACC systems. Radar cameras, GPS and V2V communication systems are used to ensure a linear formation of vehicles with spacing's of the range 30- 100 feet. To ensure safety and reliability the platooning system is formed in such a way that the truck with least braking capabilities is made the lead truck. Level 2 (L2) platooning is expected to add electronic steering, acceleration and braking controls for the following trucks, which can be manually overridden by the drivers. The system is expected to give longitudinal and lateral control over the platoon system. Level 3, 4 & 5 platoons are expected to add more complex electronic equipment and software to provide higher level of automatic maneuvering using various developing technologies.

Near-term platooning demonstration and deployments are expected to primarily fall under Level 1 automation levels and Level 2 automation category if they include both lateral and longitudinal control. Some advanced systems may extend the automation to Level 3 and higher, which require very little driver input from following trucks. Otto demonstrated a Level 4 heavy-duty truck automation system in use on a commercial delivery in Colorado in October 2016. Fig. 3 explains the different levels of automation as defined by SAE International. These higher automation levels are currently not part of near-term technology for most organizations working to deploy truck platooning. Otto is also testing a Level 2 automation system in California. Both are vehicle automation systems that may accommodate platooning functionality.

As part of the FHWA Exploratory Advanced Research Program, the California Department of Transportation (Caltrans), supported by UC Berkeley PATH, Volvo, Cambridge Systematics and LA Metro, deployed a successful truck platoon along I-580 between the towns of Dublin and Tracy in 2017. The team also conducted a closed-track testing at a facility near Montreal, Canada. The major research outcomes were that the Aerodynamic trailers in a platoon saved energy of the order of 12-14% compared to standard-trailer solo driving at a spacing less than 40 ft among them (McAuliffe et al., 2018)

2.1. Background – Texas Bridges

Texas as a result of its large geographic area of over 250 thousand square miles along with its various unique geographic features and large population accounts for the largest bridge inventory in United States with 54,338 bridges as of 2018. About 82 percentage of the bridges have been rated as good or better by TxDOT and has the lowest percentage of structurally deficient bridges across United States. Among the bridges in Texas, 35,548 bridges are on-system bridges, meaning they are located along an interstate highway or state highway and are of public importance and can witness high levels of daily traffic.

Widespread construction of Bridges in Texas started in the early 1920s and had relatively slow growth rate for the first few decades mainly due to the relatively low road traffic and the popularity of railroad networks. The great depression and the second world war almost completely stagnated the construction of bridges after mid-1930s. Road transport and bridge construction received the greatest boost during the late 1950s after the passing of the Federal Aid Highway Act of 1956, which initiated the construction of Interstate Highway systems. The influence of interstate system on growth of Texas highways is evident from the fact that 28% of on-system bridges in Texas were built during the 1950-1970-time frame.

The development of prestress concrete technologies during the early 1950s made it a natural choice of material for bridge construction in Texas due to the possibility of large-scale precast construction of the bridge girders. It was aided by the fact that, most of the bridges constructed in Texas required similar configurations with maximum span lengths varying in the range 50-100ft. As a result, nearly 65% of the highway bridges in Texas have simple span prestress beam type of construction.

The Federal Highway Administration compiles bridge information from the respective state DOTs and publishes the National Bridge Inventory (NBI) data annually. The dataset contains information about bridges and culverts in United States having a span length of at least 20 feet. Each bridge is identified by a unique Bridge Id and has 116 corresponding item attributes. The NBI data directory published by TxDOT for Texas Bridges along with the GIS data has 440 data attributes per bridge. The TxDOT directory is used for this study due to the availability of more specific information regarding each bridge, which are relevant for the study.

2.2. Impact of Overloaded Trucks on Bridges

Scott (2007) and Bourland (2011) researched the impact of Super Heavy Weight Vehicles on Indiana and Texas, respectively. Both the studies involved identification of a representative bridge, making its analytical model, load testing of the bridges for a smaller load, calibration of the analytical model using the experimental data and running analysis for higher loads using the model. The analytical model was made using SAP for the Indiana bridge study and involved analysis for 201-kip, 247.5-kip, 366-kip, 500 kip and 824 kip truck loads. It was found that the main structural elements of the bridge considered had enough strength to resist the 824-kip load, but the secondary structural elements where failing. For the Texas bridge, the analytical model was made using ANSYS software and load analysis was done for 18 different axle configurations with a maximum truck load of 252 kips. It was observed that the reserve maximum capacity of the bridges was much higher than the design ultimate moment and rating factors over 1.0 was observed for all axle configurations.

Waldron (2012), studied the effect of increasing the weight of design trucks to 97 kips from 80 kips on bridges designed using HS20 and HL93 truck loadings. The bridges were analyzed by linear-elastic and static loading cases. From the study it was observed that, the design moments and shear forces due to HL-93 loading completely enveloped the effects due to the 97-kip trucks considered. The considered truck moments exceeded the HS20 trucks moments by at least 50 percentage at all sections along the span, making older bridges susceptible for overstressing.

2.3. Impact Truck Platoons on Bridges

Devault (2017) conducted an analytical study on the effect of two truck platooning on interstate's and turnpike bridges in Florida. Two different trucks were considered for analysis, the 80-kip 5-axle C5 truck, and a hypothetical 88-kip C5 truck. Two different spacings of 30-feet and 60-feet clear bumper to bumper spacing between trucks were considered. The design rating factor was taken as the ration of operator rating to the design truck load. The platoon rating factor was taken as the product of design rating factor and the ratio of design moment to platoon moment. The material effect and deterioration effect of bridges were not taken into account during the study. A Total of 2467 bridges were analyzed. From the study it was concluded that for the 30 feet spacing scenario only 6 bridges failed for the 80-kip platoon case and 22 bridges failed for the 88-kip truck platoon case. Similarly, for the 60 feet spacing case, no bridge failed for the 80-kip truck platoon case and only 10 bridges failed in the 88 kip. truck platoon case.

Tohme (2019) studied the effect of truck platooning on load rating values of steel bridges. A single span composite steel stringer bridge as described in Manual for Bridge Evaluation (MBE) example was used as representative bridge for the analysis. Both the span length and girder lengths were varied to study their effect on load rating. Florida C5 Trucks at 20ft and 40 ft axle to axle spacing were considered with 2, 3 and 4 truck platoon cases. The bridges were rated by Load and Resistance Factor Rating (LRFR), Load Factor Rating (LFR) and Allowable Stress Rating (ASR) methodologies. It was observed from the study that for LRFR rating methodology the bridge was safe under all platooning and span configuration for 40 ft axle to axle spacing, while the bridges were unsafe for longer spans, for the 20 ft axle to axle case. When the bridge was evaluated by the ASR method, the load rating values became critical for spans as low as 90 feet for certain loading cases. For LFR rating, the bridge was safe for positive bending moment under all considered combinations. From the study, it can be inferred that, bridges designed by LFD and ASD methods are critical with respect to truck platooning (Tohme and Yarnold, 2020).

Yarnold and Weidner (2019) studied the live load effect at a truck axle to axle spacings of 20, 25, 30, 35 and 40 ft spacing of two, three and four, truck platoons. Different span configurations were also considered. All these configurations were checked using the LRFD AASHTO Bridge Design Specification, and the AASHTO Standard Specification of Highway Bridges. A C5 Truck was used for analysis within the study. The authors were able to conclude that, most of the bridges built by the LRFD specification can resist the moments due to platoons. For continuous span bridges, platoon moments were significantly higher when 3 or more platoons were considered at 20 ft axle to axle spacing, especially for spans above 150 ft.

Kamranian (2018) studied the impact of different combinations of platoons on the Hay River Bridge, near Edmonton. The bridge was selected along a potential truck platoon route and met the criteria of more than one span (3 spans) and age of more than twenty years. Dead and live load moments were determined using CSi Bridge Software and were validated using CSi SAP 2000 software. Analysis was done for 2, 3, and 4 truck platoons of both Alberta Non-Permit (NP) Trucks and Alberta Permit trucks. Analysis was also done considering multiple lane effect, here it was assumed, one lane was loaded with a permit truck and the adjacent lane loaded with a non-permit truck. From the extensive analytical study, it was found that, the bridge was safe for two-truck platoon under all loading conditions of permit and non-permit trucks. For three and four truck platoons, the truck loads had to be reduced to ensure that the live load rating factor (LLRF) was more than one. For the three-truck platoon, the value of applied moment to ultimate moment capacity ration rose up by 85.7 % for the critical NP combination.

3. CONCEPT AND METHODS

3.1. Load Ratings

The study presented herein utilizes bridge load ratings as a critical piece for evaluation of truck platoon impacts. Assumptions are made regarding the as-designed load rating methodology and IR rating value. This information is then utilized (along with other calculations) to estimate a load rating for different truck platoon configurations.

Bridge load rating is a mathematical exercise by which the strength of the bridge is evaluated. The specific outcome of the analysis is the rating factor (RF). The rating factor is the ratio of the calculated live load capacity of the bridge to the weight of the rating vehicle live load effects. The purpose of bridge rating is to provide a measure of a bridge's ability to carry a given live load in terms of a simple rating factor. These bridge rating factors can be used by bridge owners to aid in decisions about the need for load posting, bridge strengthening, overweight load allowances, and bridge closures. Bridges can be rated at two different levels, inventory rating (IR) and operating rating (OR), which are defined later. There are three main types of load rating methods, each of which are discussed separately below.

3.1.1. Allowable Stress Rating (ASR)

For the ASR method, the live loads on the structure and all other loads shall not produce stresses in the member that exceed allowable stresses. In general terms, the ASR method limits the stresses produced by service loads to predetermined values that are a percentage of the yield stress of the material. The equation used to determine the RF by the ASR method is given below (Eqn. 1). The different parameters defined are determined as mentioned in MBE 2016. In the ASR method, since the allowable stresses are controlled, the maximum capacity of the bridge section are considered at 55 percent of yield for IR and 75 percent of yield for OR.

$$\boldsymbol{RF = \frac{C - A_1 * D}{A_2 * L * (1 + I)}} \qquad \textbf{... 1}$$

Where, C is the capacity of the bridge girder, A1 and A2 are dead and live load factors, D is the moment due to dead loads, L is the moment due to live loads and I is the impact factor.

Since the capacity of a bridge is an unknown in the determination of the load rating of ASR bridges, an approximate method is presented to determine the capacity of these bridges. Based on data from literature surveys and standard plan studies, regression equations where developed to determine the approximate dead load moments in the bridge considered. These equations are based on span lengths, the determined dead load moments, along with the design HS20 live load moments. The capacity of the bridge was determined at the inventory level using the corresponding inventory level rating. The obtained capacity is then multiplied by a factor equivalent to 0.75/0.55 to obtain the capacity at operator rating level, which is then used to determine the corresponding operator rating. The procedure followed to determine the dead load moments are described below. Note that most of the ASR bridges in service are reinforced concrete, prestressed concrete girders or steel girders.

3.1.1.1.1. Regression equation for dead load moment of steel girders (Eqn. 2)

$$\boldsymbol{DL = 0.0132(LL + I) * S} \quad \textbf{... 2}$$

Hansell et.al (1971) studied the standard steel bridge girder prepared by Bureau of Public Roads, and came up with the above equation, where, DL is the dead load moment, LL is the live load moment, I is the Impact factor effect and S is the span length.

3.1.1.1.2. Regression Equation for dead load moment of concrete girders (Eqn. 3)

$$\boldsymbol{\frac{DL}{LL} = 0.6967 - 0.007620 * S + 0.0002554 * S^2} \quad \textbf{... 3}$$

NCHRP report 292 analyzed bridges up to a span length of 80 feet to develop a DL/LL relationship for concrete T beams, where DL is the dead load moment, LL is the live load moment and S is the span length of the section. The fact that, most concrete bridges have a span less than 100 ft, means the equation is valid within the scope of the study.

3.1.1.1.3. Regression Equation for weight of prestressed girders (Eqn. 4)

$$\boldsymbol{DL = -0.05S^2 + 17.476S + 258.57} \quad \textbf{... 4}$$

For obtaining this equation, standard prestress girder sections, recommended by the Prestress Concrete Institute for spans up to 140 ft was analyzed and the formula was developed, where S is the span length.

3.1.2. Load Factor Rating (LFR)

For the LFR method, the criteria are that the factored live loads and factored other loads must not exceed the (factored for concrete) nominal strength of the member. For LFR method, the effects from multiples of the live and dead loads may not exceed the maximum strength of the member. Serviceability considerations are also examined to control permanent deformations, fatigue damage, and concrete cracking from overweight vehicles. The equation used to determine the rating factor (RF) by LFR method is given below (Eqn. 5). The different parameters defined are determined as mentioned in MBE 2016.

$$\boldsymbol{RF} = \frac{\boldsymbol{C - A_1 * D}}{\boldsymbol{A_2 * L * (1 + I)}} \qquad \textbf{... 5}$$

3.1.3. Load and Resistance Factor Rating (LRFR)

LRFR was developed as a rating methodology consistent in philosophy with the AASHTO LRFD Bridge Design Specifications in its use of reliability-based limit states. The goal of the design philosophy in the AASHTO LRFD is to achieve a more uniform level of reliability in bridge design. The equation used to determine the rating factor (RF) by LRFR method is given below (Eqn. 6). The different parameters defined are determined as mentioned in MBE 2016.

$$\boldsymbol{RF} = \frac{\boldsymbol{C - \gamma_{DC} * DC - \gamma_{DW} * DW \pm \gamma_P * P}}{\boldsymbol{\gamma_{LL} * (LL + IM)}} \qquad \textbf{... 6}$$

$\gamma_{LL}, \gamma_{DC}, \gamma_{DW}, \gamma_P$ are the LRFD load factor for Live load, Dead loads, wearing surfaces and Permanent loads, respectively. DC and DW are dead load moments due to structural elements and wearing surfaces. IM is the impact factor and P is the moment due to permanent loads.

3.2. Rating Levels

In general, there are two different levels used during the rating of road bridges, Inventory level rating (IR) and Operator level rating (OR). With respect to vehicle loading Inventory rating can be defined as that vehicle load which can safely utilize a given bridge for an infinite period of life. Operator rating can be defined as absolute maximum vehicle load that the bridge may be subjected to. Various previous literatures have shown that, bridges are designed in such a way that inventory level and operator level ratings for design truck moments are over 1.0. Studies have proven that; bridges have a much higher reserve load capacity than the design moment capacities. Truck platooning is a revolutionary innovation which is still in its experimental stages. Also, the large costs involved in modifying existing trucks to be adaptable for platooning means that, truck platoon may-not become a common sight till mid 2020`s. The full-scale commercial shift of freight traffic to platoon and autonomous trucks are expected to occur after 2030 only. Considering all these factors into account, operator level rating values can be taken with respect to a platoon.

3.3. NBI Data Elements used

The research involves utilization of NBI data to determine the load ratings of the large Texas Bridge inventory. The methodology used to determine the load ratings are explained later. Here the various data elements used in the study are introduced for better understanding of the subsequent research stages.

1) Year Built (Item code 27)- This data element provides with the year in which the bridge was constructed.
2) Length of Maximum Span (Item code 48)- This data element provides with the center-to-center distance between piers, bents, or abutments measured along the centerline of the bridge. The measurement is obtained in the nearest foot.

3) Structure Function (Item code 5.1)- This data element provides with the information whether the bridge carries road traffic or pedestrian/rail traffic. It is useful in identification of the road bridges within the inventory.

4) Latitude, Longitude (Item code 16.1 & 17.1)- These data elements provides with the GPS latitude and longitude of the bridge at the beginning of the bridge in the direction of inventory. They are useful during exporting of data to Google Earth.

5) ADT (Item code 29)- This data element gives information on the average daily traffic of vehicles through the bridge. It is useful in determining the importance of the highway and in turn the probability of incorporation of platoons.

6) Structure Type (Item Code 43.1)- This data element is utilized to identify the type of member used for a particular bridge. The dead load moment equations are applied according to the member type. The data element also gives data regarding the span type of the main span of the bridge. This data is used to differentiate simple span bridges with multi span bridges.

7) Structural Evaluation (Item code 67)- This data element gives an evaluation of the structure based on the condition rating of Super-Structure (Item 59), condition rating of Sub-Structure (Item 60), and the Inventory Rating. The highest structural evaluation shall be the lowest of condition rating of superstructure and substructure.

8) Year Reconstructed (Item code 106)- This data element gives information about whether the bridge has undergone a major reconstruction. For Bridges

reconstructed, it has been assumed that the bridge has been strengthened for newer design standards.

9) ADTT (Item code 109)- This data element gives what percentage of daily traffic defined in Item 29 is truck traffic. Pickup vans and light delivery trucks are not included while calculating ADTT.

3.4. Truck types used

In order to do a comprehensive study on how the variation in truck axle configurations and wheel loadings effect platooning, six different truck types are considered for the current thesis study. The first truck type AASHTO 3S2 is a representative truck, which is similar to many commercially used trucks. They have the least gross vehicle weight (GVW) among the trucks considered and has the longest axle length. Trucks 3S2, ALDOT type and DELDOT type have the same axle configurations, but different wheel loadings. This will help in comparing the effect of wheel loading on platooning. Trucks C5, KYTC and MDOT have axle lengths decreasing with the same GVW, this set allows to study the effect of decreasing the axle lengths on the live load moments generated due to platooning. Similar studies conducted on platooning have used the truck C5 for analysis, hence the results obtained from C5 truck analysis could be used to compare with the outputs of previous studies. Use of KYTC and MDOT trucks also helps in knowing the impact of platoons, when shorter trucks carrying heavier loads ply through bridges. Figure 4 is a visual representation of the various truck axle configurations used in the study.

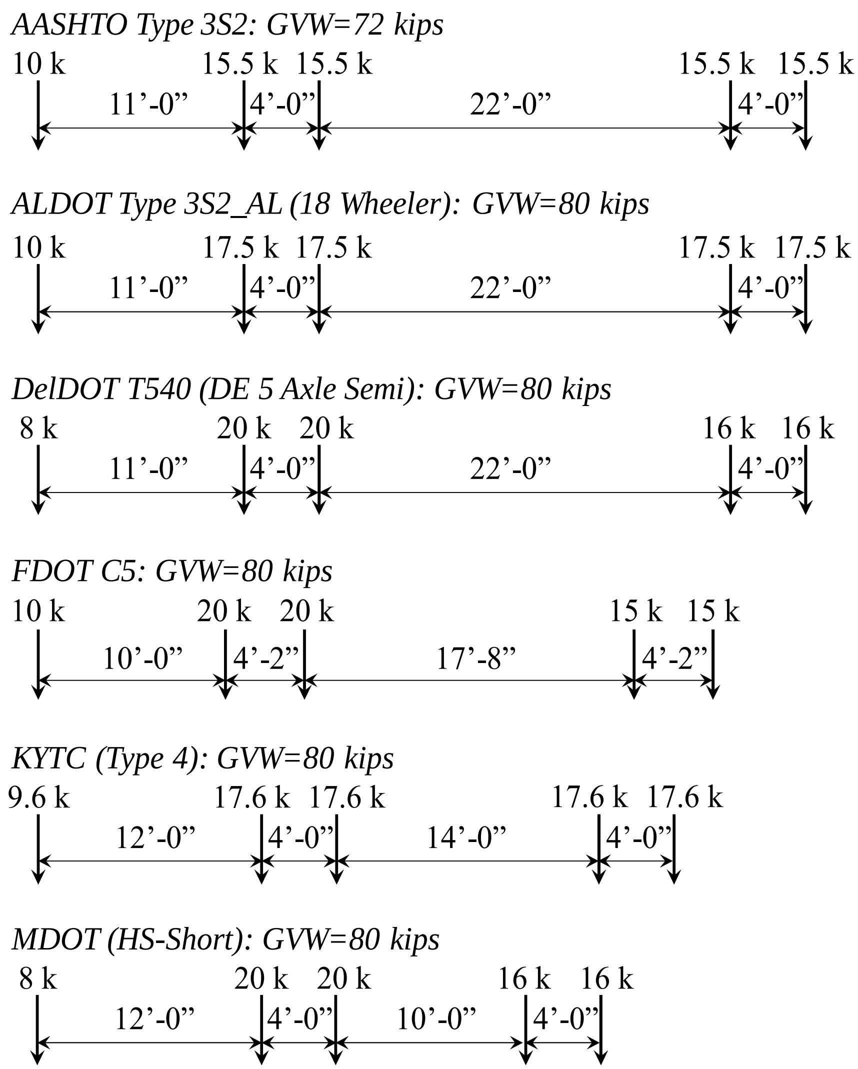

Figure 4: Various truck configurations used in the study

4. RESEARCH STUDY

4.1. Research Approach

Texas's large bridge inventory has an average age of over 40 years. Moreover, most of the bridges along the highway systems have been constructed in the 1950's and 1960's using predominantly the ASD method and few by the LFD method. The LFD method has been used for rating on system bridges other than timber bridges since 2000. Over the last 14 years most bridges have been designed using the LRFD method. Risk assessment of bridges based on its original design methodology can be a cause for significant error. Hence in this research an equivalent risk-based approach is taken into account, where the original load ratings are converted to its corresponding LRFR ratings. The approach followed in this research consists of five stages. Figure 5 shows the visual representation of various stages in the research.

Stage 1: Background Analysis - Refined load ratings are determined for select existing bridges and standard bridge designs, by all three methods of rating, to establish assumptions for future stages.

Stage 2: NBI Data Analysis - The NBI data is filtered to obtain the selection of bridges most likely to foresee truck platoons. In addition, supplemental analysis was performed on multi-span steel girder bridges.

Stage 3: Load Rating Analysis – In this stage the obtained approximate inventory ratings from stage 1 and bridge information from stage 2 is utilized to determine the approximate operator rating of the bridges in Texas.

Stage 4: Risk Assessment - A relative risk index is identified by converting the load ratings to equivalent LRFR ratings based on the available literature and then applying the effect of bridge condition.

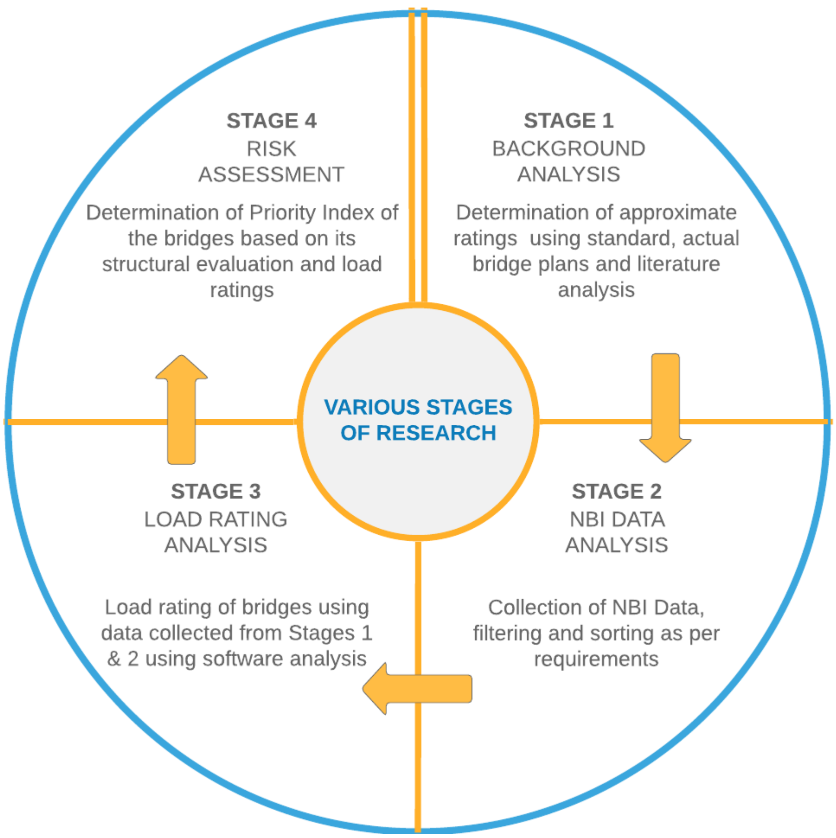

Figure 5 : Stages of Research

4.2. Stage 1 – Background Analysis

One of the critical assumptions to obtain the estimated truck platoon load ratings is the original inventory design rating of existing bridges. Actual bridge plans obtained from TxDOT were studied in detail and approximate inventory and operator rating of different types of prestressed concrete and steel type bridges were obtained. The data available from various literature was also considered during this stage to obtain an approximate initial inventory rating to be assumed for the rest of the study. In order to validate the conversion factors from different design methods to LRFR method, the standard TxDOT girders and the actual girder plans obtained were analyzed by all three methods of design and the corresponding design operator ratings were obtained.

4.2.1. Analysis of Prestressed Concrete Bridges

Before the initiation of load rating analysis based on the obtained plans of prestressed concrete bridges, the standard prestressed girder details for varying span length were obtained from TxDOT. Girder detail data tables from 2018 were used for the LRFR study. Similarly, data tables from 1974 and 1965 were used to evaluate prestressed concrete beams by LFR and ASR method simultaneously. A total of 63 standard Girder data (36 LRFR, 27 LFR/ASR) and 10 (5 LRFR, 5LFR/ASR) actual bridge girders were evaluated in this section of the study. The LRFR bridges were evaluated according to the provisions of AASHTO LRFD Bridge Design Specification. LFR bridges were evaluated by AASHTO Standard Specification for Highway Bridges 1973. ASR bridges were evaluated using the commonly used 1969 Ultimate Design Criteria of the Bureau of Public Roads (BPR) criteria. Bridges load rated using LFR and ASR methods were also load rated using LRFR method to make a comparison with assumed conversion factors. All the bridge plans were rated for inventory and operator ratings and the ratios were calculated and compared. In general, the inventory ratings obtained for prestressed girders were much higher than one. This is mainly due to the fact that, for prestressed girders in most cases, it is the stress criteria that governs over the ultimate moment capacity criteria.

Table 1: Prestressed girder design load rating results

	No: of Girders	Mean IR Rating	IR Less Than 1	IR Less Than 1.35	Lowest IR Rating
LRFR Standard Plans	44	1.62	0	1	1.28
LFR Standard Plans	12	1.70	0	0	1.50
ASR Standard Plans	23	1.67	0	5	1.12
NCHRP 122	7	1.67	0	0	1.38
Actual Girders (LRFR)	5	1.78	0	0	1.57
Actual Girders (LFR)	5	2.12	0	0	1.73

For prestress girders designed by LFR/ASR methods, inventory rating is calculated by stress criteria as well as by the capacity of section method. For comparison purposes the LFR standard girders were analyzed by both methods to obtain the inventory rating. While the average inventory rating obtained by section capacity method was 1.70, the inventory rating obtained was only 1.13 when tension was prevented in the section. As the tendon profile is required to accurately estimate the inventory and operator ratings by this method, the section capacity method is used in further part of the research. From Table 1 it could be inferred that the average observed inventory level rating for prestressed bridges are of the range 1.65 to 1.70. A conservative representative IR rating of 1.35 was then chosen for the further analysis of prestressed bridges based on a 90-percentile standard deviation of the entire set.

4.2.2. Analysis of Steel bridges

In the case of steel bridges, as described earlier, most of the bridges are of multi-span type. As a result, the capacity of the steel girders to resist positive and negative moments were taken into consideration. For bridges rated by LRFR method, the method mentioned in Appendix D6 of AASHTO LRFD Bridge Design Specifications has been used to determine the moment capacity at positive and negative flexure. The effect of deck reinforcements was considered to be zero as a conservative assumption. Capacity of the section in LFR/ASR method were determined by assuming composite section properties and then determining the maximum flexural capacity as per AASHTO Standard Specification for Highway Bridges 1973 and State of Texas- Specifications for Design of Structures 1935 respectively. The maximum allowable stress was limited according to the provisions of the respective provisions.

Table 2: Steel girder design load rating results

	No: of Girders	Mean IR Rating	IR Less Than 1	IR Less Than 1.1	Lowest IR Rating
LRFR Standard Plans	47	1.22	0	4	1.01
NCHRP 122	38	1.49	4	7	0.90
Schelling et.al (1984)	16	1.65	0	0	1.36
Actual Girders (LFR)	9	1.27	0	0	1.17

A total of 40 standard LRFR girders and 12 (5 LRFR, 7 LFR/ASR) actual steel bridge girders were load rated. The load ratings of steel girders determined by Schelling et.al

(1984) and NCHRP Report 122 were also considered. Table 2 shows the obtained mean IR ratings by actual study and literature study. Based on the mean and standard deviation obtained a 90th percentile IR rating of 1.10 was fixed for further analysis and design.

4.2.3. Stage 1 Findings

From the analysis of bridge girder plans, it was observed that for all the girders considered, the design inventory rating based on the girder capacities, is much higher than one for both steel prestressed concrete girders. Hence the initial assumption of inventory rating of one for all bridges is modified. The mean and standard deviations of inventory ratings for steel and prestressed concrete bridges are determined and a 90% confidence interval is considered. The initial inventory ratings assumed for the further stages of the study are 1.35 for prestressed concrete bridges and concrete bridges and 1.10 for steel bridges.

4.3. Stage 2 – NBI Data Analysis

The second stage of the study involves filtering of the available NBI data to relevant data sets and bridges. As described earlier, Texas has a large inventory of nearly 55,000 bridges of which nearly more than half the bridges are located along by roads, through which platoons may never travel through. In the TxDOT NBI data inventory, information regarding STRAHNET status of each bridge is available. STRAHNET refers to the Strategic Highway Network of the United States, which comprises mainly of the interstate highways, their feeders and connection roads to ports, airports and military installations. These roads are highly likely to witness truck platoons in the immediate future and are those considered in this study. This helps in further reducing the data set to nearly 8,000 bridges. In order to refine further, bridge with a span less than 50 feet are ignored. This is done based on the fact that, in most cases a minimum span length of 60 feet is required to produce live load platoon moments greater than that caused by a single truck passing through the same bridge. Bridges with daily truck traffic less than 100 are also filtered out. These filtering maneuvers reduces the total number of analysis bridges to 6,550. Further filtering is done to remove timber bridges, arch bridges and other similar types of special bridges (Item 43.1- member type 41-99). This is done because in most of the cases, the design of these bridges are different from the standard procedures and would require specific inventory level analysis to know their capacity and live load behaviors, which are beyond the scope of the study. This further reduces the number of bridges to 6,100.

From the NBI data analysis it was observed that more than 60 % of the steel bridges have a multi span configuration. From the NBI data, details regarding the maximum span length and number of main spans can be obtained. The information regarding each span length for multi-span bridges or the number of spans in each continuous span is not available. Since there are over 1850 multi-span steel bridges, an assumptive method was used to determine the effective live load effects of truck platooning on multi-span bridges. For both LRFD and LFD bridges, it was observed that the impact of maximum negative moment variation is much higher than the maximum positive moment variation. It was assumed that, the maximum span length is the span of all sections within the continuous bridge and the number of main spans were assumed to be the number of continuous spans in a unit. SAP 2000 software was used to do the multi-span analysis. Analysis was done for the 6 trucks considered and for 3 different truck spacing's of 25, 30 and 40 feet's respectively. The ratio of maximum live load moment due to the platoon and the design live load was calculated for maximum positive and negative moments. The ratio values where determined for span lengths varying from 50 to 175 feet and number of spans varying from 2 to 4. Based on the analysis results, equations were developed to represent the ratio variation along span length for each truck type at a particular truck to truck axle spacing.

From the multi-span analysis for truck platoons, it was observed that the maximum moment diagrams for truck platoons, varied significantly from that of design trucks. The fact that platoons are live load trains of length range 150 to200 feet means that, for multi-spans the platoons are contained entirely within the bridge spans and hence producing greater live load moments at the midspan and support regions. The negative moments generated at support regions in multi span bridges where observed to be similar to the maximum moment for the simply supported case for many span length and truck configuration cases. Based on the above two observations, it was decided to limit multi-span effect consideration to a maximum span length of 175 feet for each multi-span girder. For bridges having maximum span length greater than 175 feet, it is assumed that the moment generated is equal to the maximum simply supported span moment. A sample moment ratio output of multi-span study is shown in Appendix B

4.4. Stage 3- Load Rating Analysis

Based on the filtered bridge data, load rating analysis was performed to calculate an approximate load rating for the filtered STRAHNET bridges in Texas for various truck platoon configurations. An Excel tool and a MATLAB tool were developed to do the load rating analysis. For multi-span bridges live load moments were calculated using SAP2000 software and the results were added to the Excel and MATLAB tool as coefficients, which are described later.

Considering the large size of the available bridge inventory to be assessed, a simplified approach has been taken for the load rating procedure. Assumptions have been made in such a way that it satisfies a broad spectrum of the bridge inventory to be analyzed. The assumptions made were:

1) All the prestressed concrete girder bridges are assumed to be simply supported. This span configuration is used by 98% of prestressed girder bridges within Texas. Even though the bridge decks may be continuous, the beams are still simply supported and hence the rotational restraint at the supports is negligible.
2) More than 60% of the steel bridges have a continuous span, hence a modified moment calculation procedure has been followed, as explained earlier.
3) The inventory rating of all the bridges are assumed based on the analysis performed in Stage 1. For this research it allows for determination of the capacity of the bridge.
4) Impact factor for truck platooning and for design trucks are assumed to be the same.

5) The effect of age deterioration, potential loss of capacity due to fatigue or other causes are only considered through the NBI structural condition rating.
6) It is assumed that only the platoon trucks are on the bridges. That is, the lane loading effect due to smaller vehicles is ignored while determining operator ratings.
7) It is assumed that flexure controls the load ratings. Historically most bridge designers ensured that shear did not control.

For both LFR and LRFR rating methods, the numerator in the rating equation is assumed to be constant (shown in Equation 7 and 8), as the dead loads and capacity remain a constant for both operator and inventory rating methods under all general conditions. Where A is a constant equivalent to ultimate capacity minus the factored dead load moments acting on the section of the bridge.

$$\boldsymbol{RF_{LFR}} = \frac{\boldsymbol{A}}{\boldsymbol{A_2 * L * (1+I)}} \qquad \textbf{... 7}$$

$$\boldsymbol{RF_{LRFR}} = \frac{\boldsymbol{A}}{\boldsymbol{\gamma_{LL} * (LL+IM)}} \qquad \textbf{... 8}$$

8) For ASR method, the stress levels used to determine bridge capacity is different for inventory (55 percent yield) and operator (75 percent yield) ratings. Hence the inventory level capacity of the bridge is found approximately as the sum of design live load moment including the effect of impact loading plus the moment due to dead loads (based on the assumption IR is one). The obtained capacity is then multiplied by a factor 1.36 (0.755/0.55) to obtain the approximate capacity at operator level.

4.4.1. VBA Program Flow Procedure

An Excel tool developed capable of analyzing up to five truck platoons of any axle configuration and truck-to-truck spacing was developed. The Visual Basics for Applications (VBA) programming language platform available within Excel has been used to automate the analysis and output generation. Excel macro codes were used within VBA to repeat the given inputs for all the bridges and obtain the output result. The bridges are identified by their Freight Corridor number. Freight Corridor number refers to the designated highway number allocated to different routes within Texas by TxDOT. The direct corridor number data is not available from NBI data; hence ArcGIS software is used to obtain the same. A map layer of Texas Freight Corridors is overlapped over the Texas bridges layer map. The data is clipped based on the bridge ID and saved as an Excel file, which is then added to the Excel tool. In order to facilitate easier determination of the load rating data of the bridges after filtration, the following program flow procedure has been utilized:

1) Input the Bridge Id/Route Number, truck axle configuration and number of trucks in the platoon.
2) Identify the bridge based on its Bridge Id/Route number using the NBI data.
3) Record max span length, year constructed/reconstructed and structure type data of the bridges.
4) Determine the method used for design of the bridge based on the year of construction (ASD/LFD/LRFD).

5) Determine the maximum design live load moment using the corresponding design truck and maximum span length.
6) Determine the capacity of the LFD and LRFD bridges using the assumed inventory rating and structure type. For ASD bridges determine the capacity using the estimated expressions described earlier
7) Determine the maximum live load moment due to the truck platoon load configuration entered.
8) Determine the operator rating of the bridge for platoon trucks.

Figure 6 is a flow diagram of various steps involved in stage one of the research

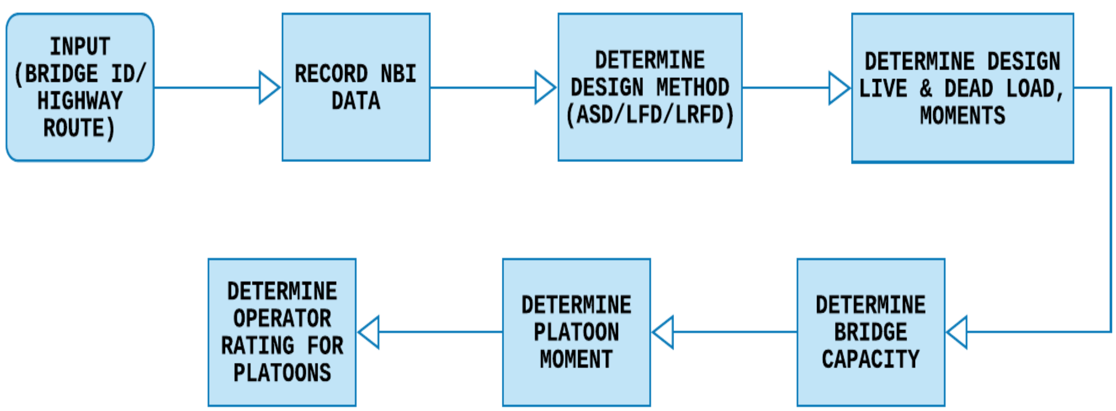

Figure 6: Flow diagram of Steps in Stage 1

4.4.2. MATLAB Analysis

In order to facilitate faster analysis of all the bridges simultaneously, a MATLAB program was developed. The program follows a similar coding flow as the VBA code. In order to facilitate faster calculations, three separate spreadsheets where linked to the MATLAB code. The first sheet consisted of the NBI select data element details and the second sheet consisted of moment data for spans 40-500 feet at 5 feet intervals for all the truck combinations and spacing considered for the study. The moment values were pre-determined to reduce the computation time. The third sheet consisted of the various moment ratios to be used for the multi-span analysis. Conditional loops were used to segregate bridges based on span type, age and material. The outputs were printed on to another spreadsheet file for easier post analysis. The MATLAB code used in the study is shown in Appendix C

4.4.3. Initial Results

Figure 7 and Figure 8 are samples of data analysis results for LRFR and LFR methods based on the entire Texas Bridge Inventory. The graphs show the operator rating by LRFR and LFR rating methods for 2 truck C5 platoons at an axle-to-axle spacing of 30 and 40 feet respectively. The number of bridges in each span range are also shown, for better understanding of the data. It is to be noted that, for a platoon configuration with the increase in span length, the rating factors decreases initially and then increase after a threshold span length. From the figure, it can be seen that for both old and new bridges, most of the bridges have a maximum span length less than 140 feet, the commonly used maximum length of a prestressed concrete girder bridges.

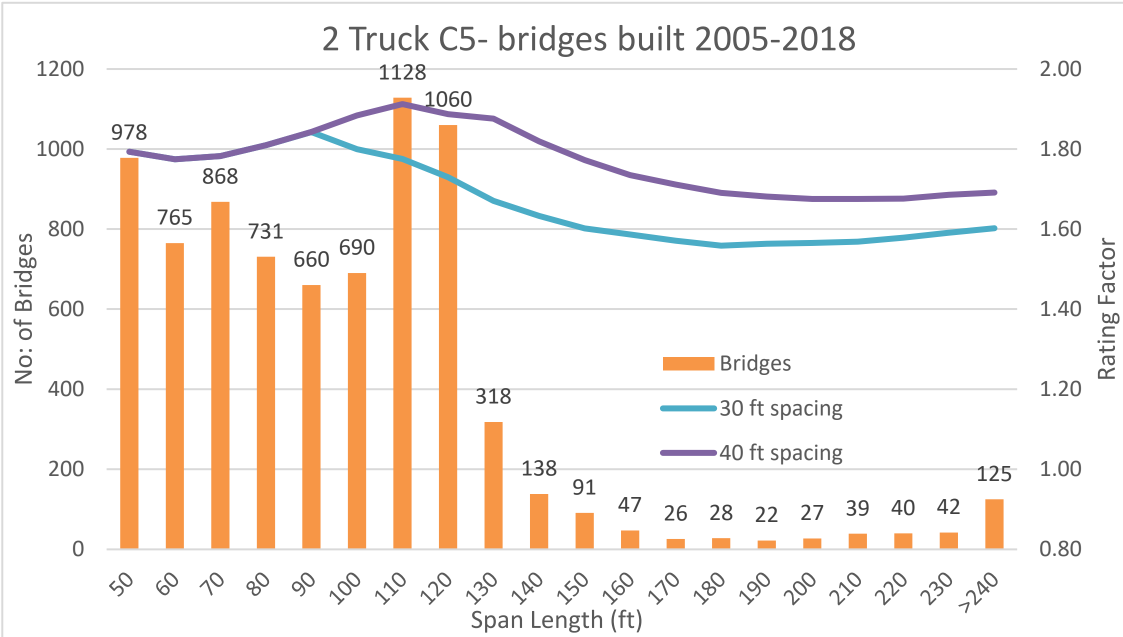

Figure 7: Sample analysis data graph for bridges built by LRFD method

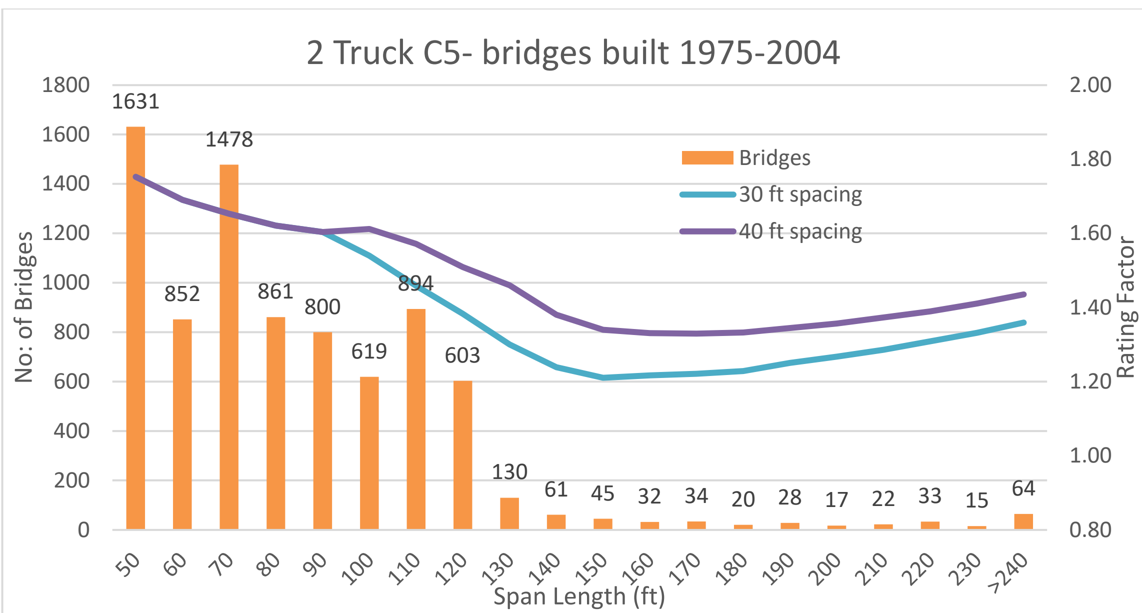

Figure 8 : Sample analysis data graph for bridges built by LFD method

Figures 9 to 12 are a comparison of the platoon to design truck moment ratios with bridge span length for different platooning configurations. All truck types irrespective of the platoon configuration has a constant moment ratio up to a span length of 90 feet (90 feet can be considered the minimum bridge length required to generate excess moments due to platooning). For both 3S2 and C5 type trucks, when compared to LRFR bridges, the moment ratio obtained is below 1.0, hence the subsequent operator ratings will be well above 1.0. Whereas the moment ratios obtained when compared to HS20 (LFR) design trucks are more than 1.0 and hence, it is likely that the operator ratings obtained on analysis may be less than 1.0. From the comparison graphs it can be concluded that bridges built prior to 2004 (LFR/ASR) are more susceptible to overload failure due to the crossing of platoons, especially if they do not have good structural condition, It is observed that for a particular truck, the effect of 2 and 3 truck platoons are constant up to a certain span length, beyond which they diverge. For 3S2 type trucks, for a spacing of 30 ft between trucks, the effect of 2 and 3 trucks are same up to a span length of 155 ft. Considering the fact that most of the bridges within Texas Inventory have a span length less than 150 ft, the effect of 2 and 3 truck platoons will be same for 3S2 trucks in most conditions.

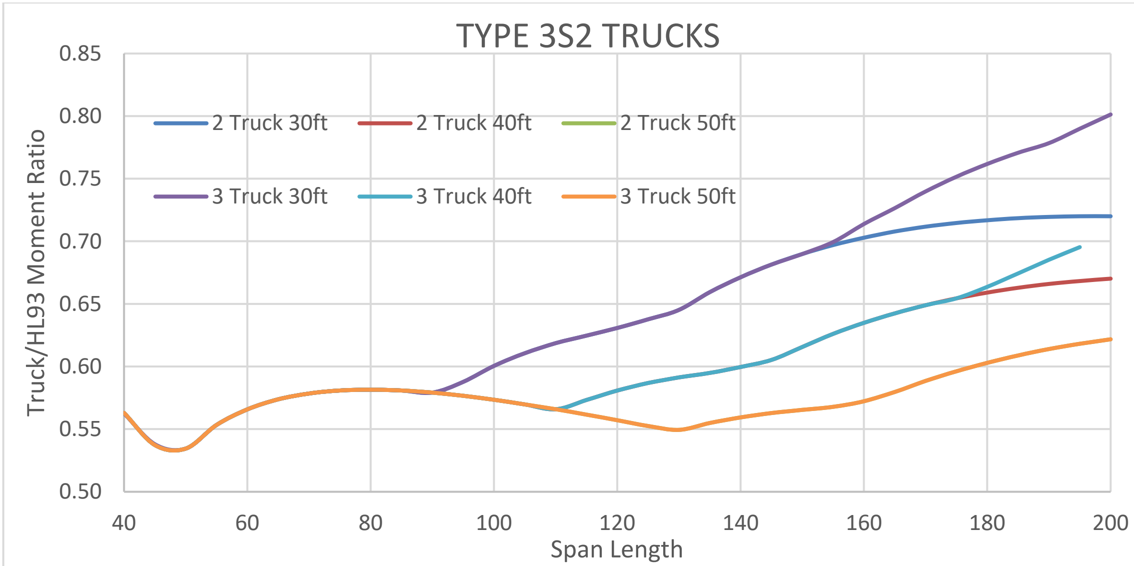

Figure 9 : Graph showing variation of the 3S2 truck moments with respect to HL93 design moments.

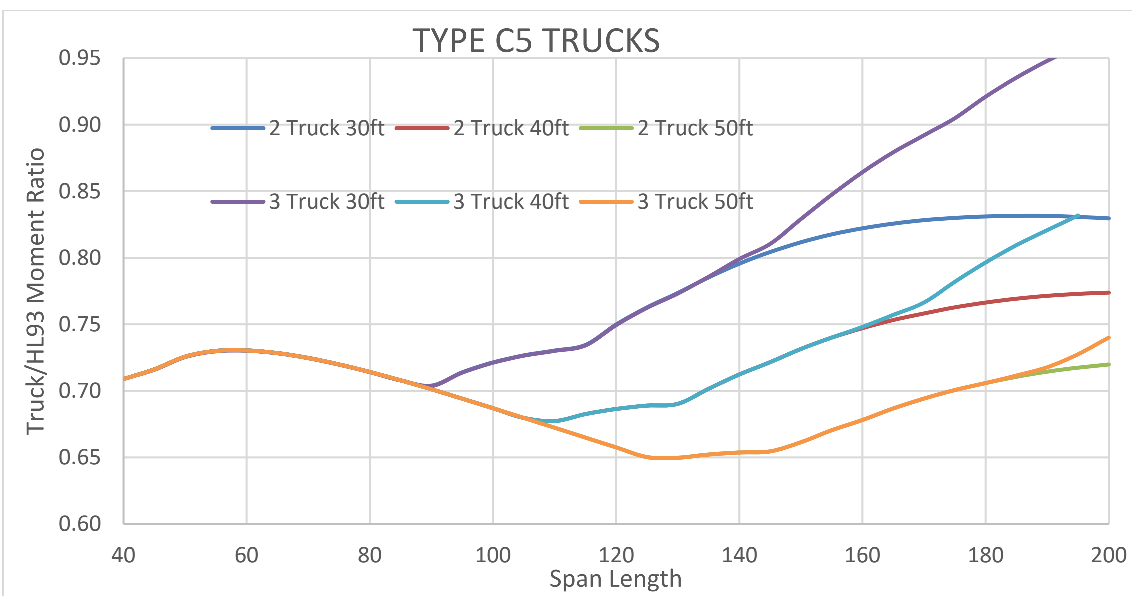

Figure 10 : Graph showing variation of the C5 truck moments with respect to HL93 design moments.

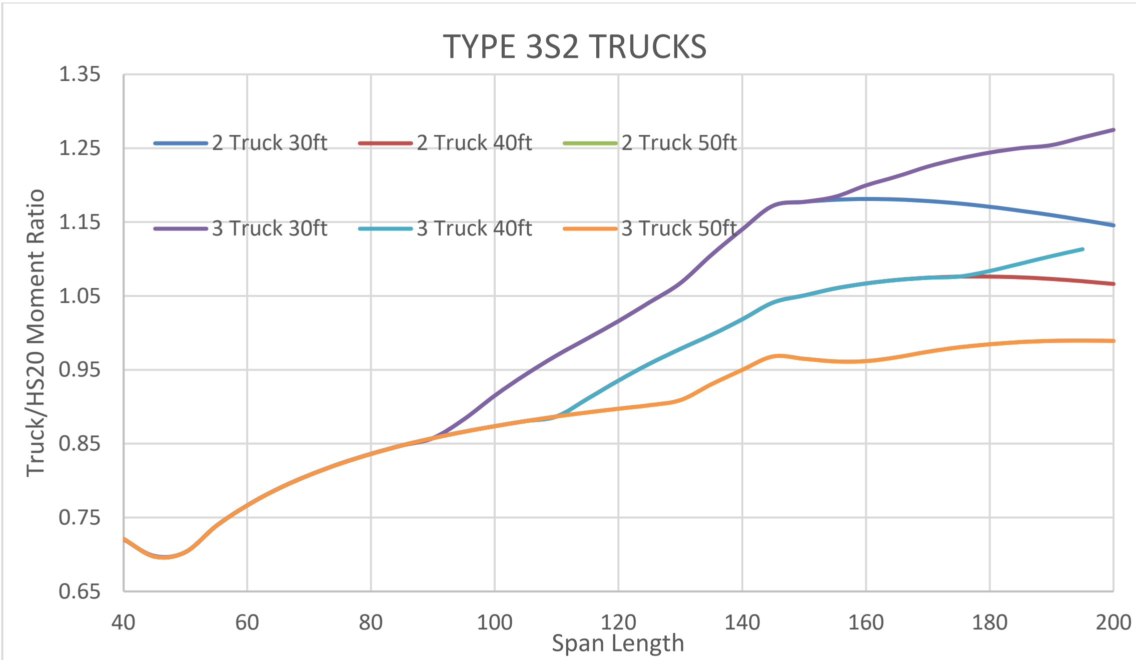

Figure 11 : Graph showing variation of the 3S2 truck moments with respect to HS20 design moments.

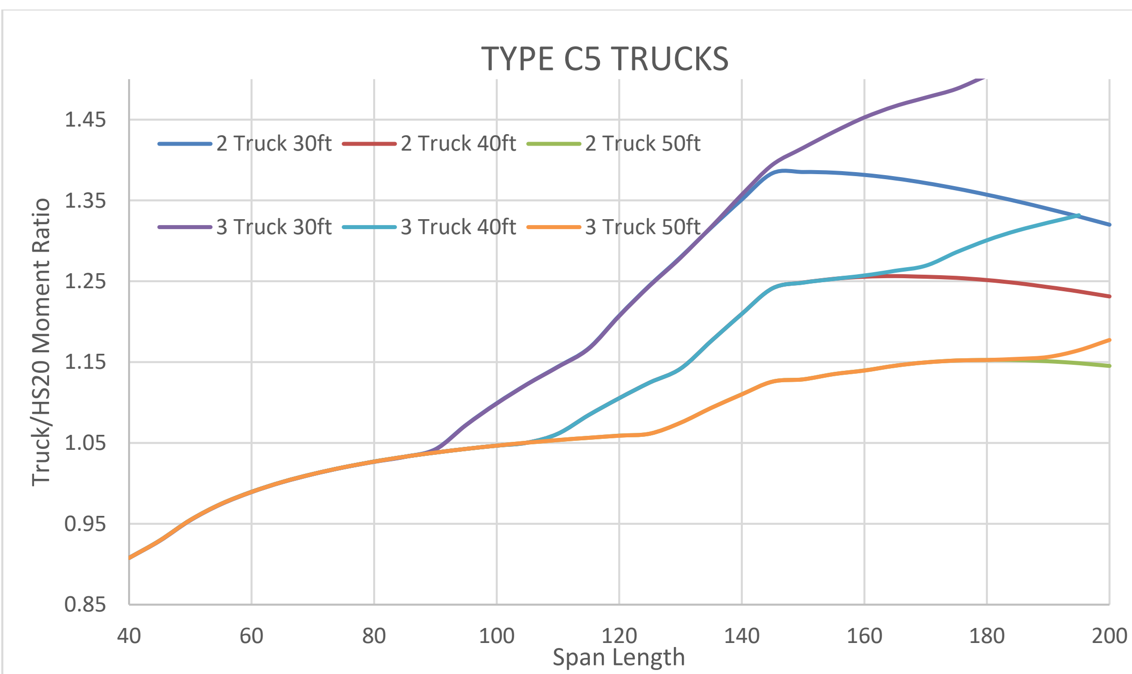

Figure 12: Graph showing variation of the C5 truck moments with respect to HS20 design moments.

4.5. Stage 4- Risk Assessment

In this stage of risk assessment, the obtained operator ratings are then converted to the corresponding load rating by the LRFR method for all bridges, irrespective of their original rating method and method of design. FHWA is currently under the process of converting all load ratings of on-system bridges to LRFR bridges. Hence, in order to be at consensus with the process, ratings obtained by LFR and ASR method are converted to LRFR ratings based on conversion factors, described in the following section.

4.5.1. LFR to LRFR Conversion

Due to the unavailability of exact bridge data to load rate by both methods, similar studies conducted by other authors has been referenced to obtain the conversion factors. NCHRP Report 122 (2005) and NCHRP Report 700 (2011) are two studies that were conducted in order to compare the load rating variation of bridges by LFR and LRFR methods. Both the studies are of similar nature in which, the load ratings where done analytically using AASHTO Bridge rating software's VIRTIS and AASHTOWARE, respectively.

NCHRP 122 report focuses on providing a comparison between ratings generated by LRFR method and LFR methods. The comparisons were based on flexural strength and only the interior girders were considered. 74 representative bridge plans obtained from NYSDOT and WYDOT were analyzed in the study to obtain the comparison. The study included 44 steel plate girder/rolled beam bridges and 17 prestressed girder type bridges. All the bridges were load rated at inventory and operator level using design trucks as well as type 3S2 trucks. From the study it was also observed that, for all the bridges analyzed the inventory level load rating was greater than 1.0, validating the initial assumption.

NCHRP 700 involved an extensive of study of bridge load ratings which included bridges from 8 states. Detailed bridge data of 18,037 bridges were collected. 1,500 bridges with a total of 3,043 girder sections where analyzed in detail for 12 vehicle combinations each. The filtration of the bridges to 1,500 was done in such a way that, it represented all the commonly used type of bridge types in United States, with bridges from different periods of constructed, ensuring it is a highly representative set of American bridge inventory. A total of 704 prestressed girders and 1,430 steel multi-girders were analyzed as a part of the study. In the analysis section shear and moment ratings of the different types of girders were compared by LFR and LRFR inventory rating as well as a reliability study was also conducted. From the data analysis of the in-depth report of the study, it was observed that only 12 (1.7%) out of the 704 prestressed I-girders had a LFR rating less than 1.0. Similarly, there were only 70 (4.9%) steel girders with a LFR rating than 1.0.

The data from both documents have been taken together and a weighted average has been used to obtain the final conversion factor from LFR to LRFR. The factors are shown in Table 3

Table 3: LRFR conversion factors

Rating Method	LRFR Conversion Factors	
	Steel Bridges	Concrete Bridges
LRFR	1.00	1.00
LFR	0.77	0.50
ASR	0.88	0.47

4.5.2. ASR to LFR Conversion

Similar to the conversion of LFR to LRFR ratings, bridges rated by ASR method had to be converted to LRFR rating. Direct literature reference on conversion of ASR to LRFR ratings was not obtained, hence factors were determined to convert ASR ratings to LFR ratings based on available literatures. Then the conversion from LFR to LRFR was performed in the manner illustrated in the earlier section.

Schelling et.al (1984) compared the load rating values of 16 steel girder type bridges in Maryland by LFR, ASR and Auto Stress method of rating. 8 bridges were of simple span type while the remaining bridges where multi-span type. The authors also developed a regression equation to convert ASR ratings to LFR ratings. From the study it was observed that the average rating by LFR was more than ASR method for steel bridges by about 16 %. The inventory level ratings were observed to vary between 1.2 and 1.6 for all the bridges.

In MCHRP Report 91-1 (1994) 73 bridges (33 Concrete & 40 Steel bridges) were load rated by LFR, ASR and Strength method of rating. The bridges used for study were bridges that were identified as bridges that required posting or were on the verge of being posted based on ASR method. Due to this fact, the average inventory rating observed for the bridges was less than one. For steel bridges, the observed LFR ratings were higher than ASR ratings, while for concrete bridges, ASR ratings were higher.

The data from both literatures has been taken together and weighted average method has been used to obtain the final conversion factor from ASR to LFR. The factors are shown in Table 3.

Table 4 shows the operator rating obtained by analysis of the obtained prestressed girder plans by all the three methods of rating. Bridges constructed by ASR and LFR methods were rated by all three methodologies. Older bridges showed a lower operator rating due to the fact that ASR and LFR bridges were designed for HS20 loading while LRFR bridges were designed for the much higher HL93 loading. The ratios obtained are slightly higher than the values obtained based on literature reference. Hence the literature values can be considered conservatively.

Table 4: Operator Rating ratio obtained by actual plans

Design Rating Method	Operator Rating			$\frac{LRFR\ OR}{DESIGN\ OR}$
	ASR	LFR	LRFR	
ASR	2.73	2.79	1.62	0.59
LFR	2.82	2.89	1.65	0.57
LRFR	-	-	2.12	1

4.5.3. Application of NBI Condition Ratings

Upon obtaining the equivalent LRFR operator ratings for each bridge, possible reduction in capacity due to age or other factors are taken into account by applying the effect of bridge condition. Due to the large size of data set to be considered, individual assessment of each bridge is not possible. NBI data includes a data attribute called structural evaluation rating, which as described earlier is a direct indicator towards the condition of each bridge. NBI coding manual describes how to interpret the corresponding effective bridge load rating based on its structural evaluation rating.

Table 5: Appraisal Evaluation Rating factor

Appraisal Rating	>7	7	6	5	<5
Multiplication Factor	1	0.85	0.75	0.60	0.50

The manual defines the maximum permissible truck load that can traverse through the bridge based on its appraisal rating. In the current research study, the truck loads converted to equivalent rating multiplication factors. The conversion is done by dividing the allowable load by the original design load for which the bridge was designed. Table 5 gives the multiplication factors used to convert the obtained operator ratings from Stage 3 to the effective operating rating (EOR) taking into account bridge condition.

4.6. Bridge Prioritization

After completion of load rating analysis, the bridges were prioritized according to their equivalent operator rating (EOR). Prioritization of the bridges help in the identification of high priority routes based on the relative risk. Five priority levels were developed. Level 1 priority bridges has the lowest level of relative risk and are unlikely to have any issues carrying truck platoons. Conversely, the Level 5 bridges indicate those with the highest relative risk to support truck platoons long-term. Level 5 bridges are not necessarily unsafe. However, these structures should be those investigated first if they are to support sustained truck platoon traffic. Table 6 shows the EOR ranges for each priority level.

Table 6: Priority Levels

Priority Level	Effective OR
1 (low)	EOR > 1
2	1 > EOR > 0.9
3	0.9 > EOR > 0.8
4	0.8 > EOR > 0.7
5 (high)	0.7 > E0R

4.7. Visualization

In order to aid better representation of the results, the output files were exported to Google Earth. The availability of exact GPS coordinates from NBI data helps in placing the bridges at their geographic locations. Prioritization also enables color coding of bridges in Google Earth based on the relative risk. The Level 1 (low priority) bridges are coded as green with the Level 5 (high priority) coded as red. Figure 13 shows a sample data output obtained after VBA analysis. Figure 14 to 16 show the data output represented visually in Google Earth in different forms.

Bridge ID	Highway District	Span	Year Built/ Rebuilt	Bridge Category	Operator Rating	Net OR	Priority Index
100930049507254	10	65	1966	prestress concrete girder	2.81	1.12	1
100930049507256	10	65	1966	prestress concrete girder	2.81	0.99	2
100930049507279	10	70	1967	steel girder	1.52	0.88	3
100930049507280	10	45	1987	concrete bridge	3.23	0.96	2
102120049505177	10	95	1964	steel girder	1.61	0.74	4
102120049506239	10	65	1966	prestress concrete girder	2.81	0.79	4
102340049502010	10	60	1963	steel girder	1.61	0.74	4
102340049502312	10	95	2000	prestress concrete girder	2.55	1.07	1
102340049503001	10	75	2005	prestress concrete girder	3.01	2.56	1
102340049503096	10	45	1962	steel girder	1.92	0.89	3
100930013801122	10	80	2005	prestress concrete girder	3.01	2.56	1
102120049504054	10	70	1961	steel girder	1.52	0.88	3

Figure 13 : Sample output obtained on VBA analysis

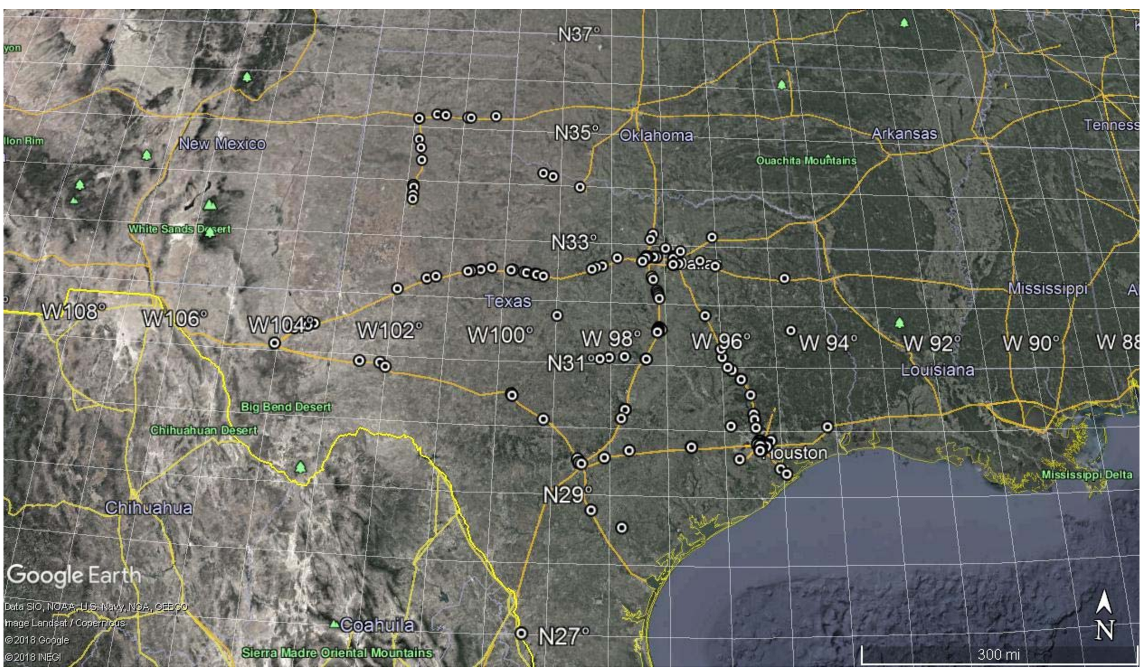

Figure 14 : Google Earth visualization of high priority bridges for type 3S2 trucks under 3 truck, 30 feet spacing combination

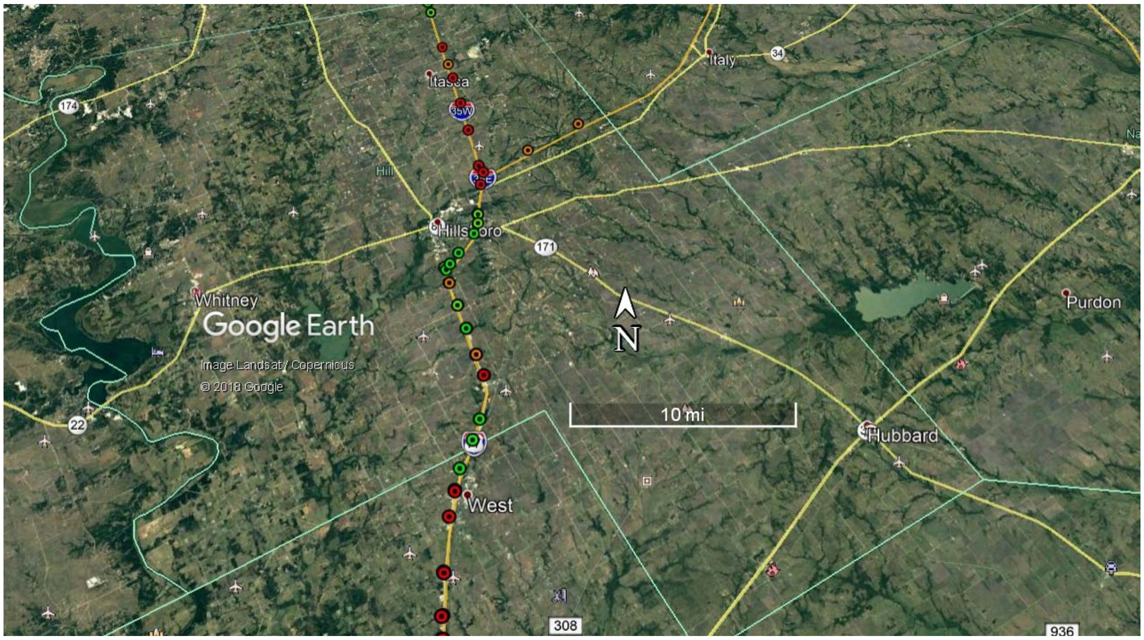

Figure 15 : Google Earth visualization of a color-coded section of Inter-State near Hillsboro, Tx

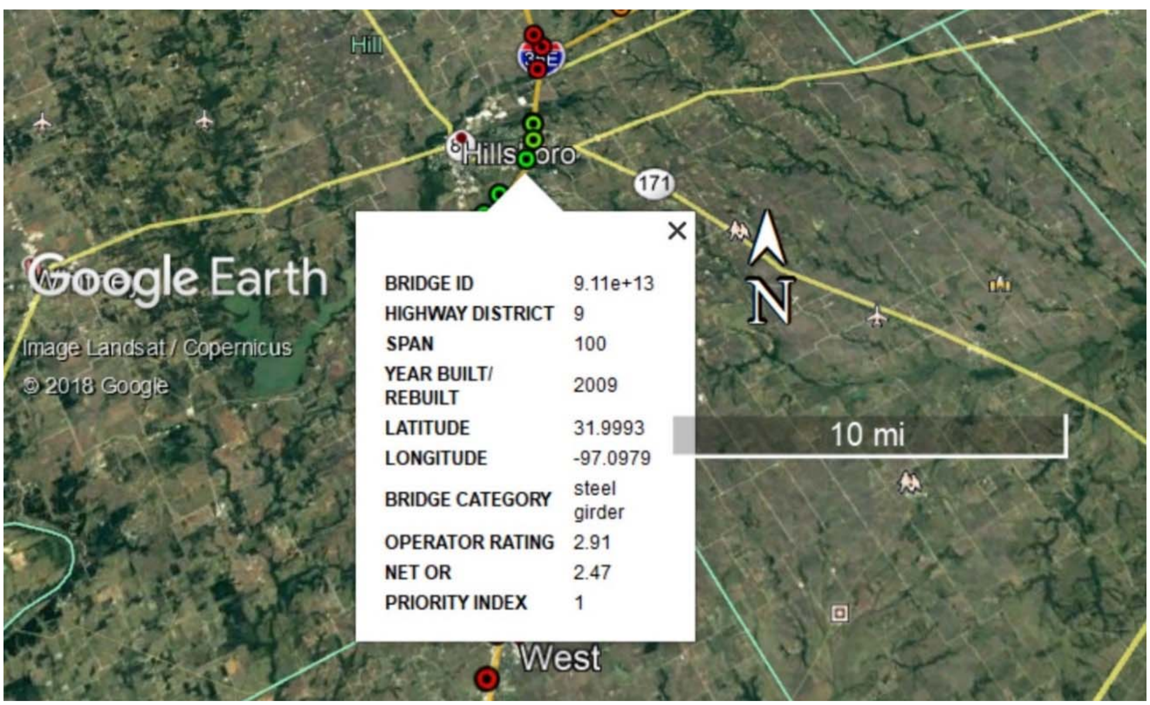

Figure 16 : Google Earth visualization of color-coded section of Inter-State near Hillsboro, Tx with a bridge selected

5. ANALYSIS INTERPRETATIONS

In order to aid better representation of the outcomes, the results are presented separately based on the three governing parameters: truck spacing, bridge span length, truck type and number of trucks in the platoon. In addition, the prestressed girder and steel girder bridge results were compared. Each are presented separately below.

5.1. Impact Based on Truck Spacing

Figure 17 shows the variation in the percent of high priority (Level 5) bridges obtained on analysis of the 6,550 STRAHNET bridges. For all the truck types, the largest percentage of high priority bridges were obtained for a truck axle-to-axle configuration of 25, 30, 40 and 50 feet. For all the trucks, the variation is roughly parabolic with respect to increase in truck spacing. The percentage of high priority bridges decreased by 23 %, 45 % and 56 % on an average when the truck spacing increased from 25 to 30, 40 and 50 feet respectively. There are several reasons as to why the percentage of high priority bridges do not go to zero. It was observed that about 30 % of the high priority bridges for each truck type were independent of the platoon spacing and dependent only on the truck type. This is due to the fact that more than 15 % of the total bridge inventory considered has a maximum span length less than 75 feet, and hence two trucks being on top of the bridge together is not possible. The consideration of the structural condition factors is also a reason behind a fixed minimum percentage of high priority bridges irrespective of the platoon spacing.

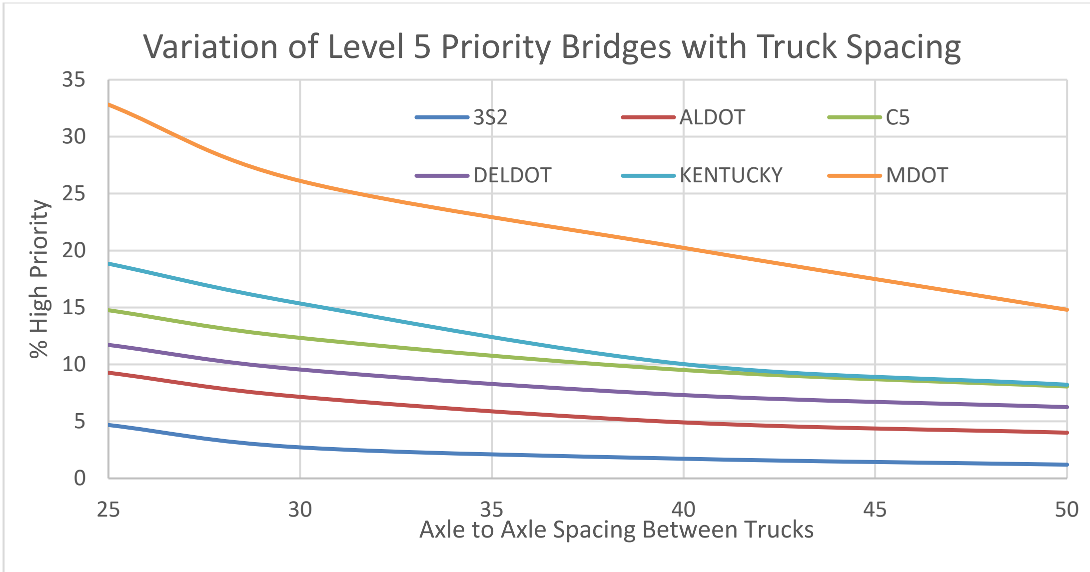

Figure 17 : Variation of percentage of high priority bridges with platoon spacing

Figure 18 is a visual representation of how the number of bridges in each priority category change with the condition applied. C5/3S2 refers to the truck type, 3 refers to the number of trucks in platoon and 30/50 refers to the spacing between the trucks (30 ft or 50ft). It is to be noted that 3S2 truck type at a spacing of 50 ft is almost representative of the exiting road conditions when two trucks cross a bridge with a close spacing. While C5 truck type at a spacing of 30 feet is representative of a future heavier tuck type moving in a platoon spacing of 30 feet.

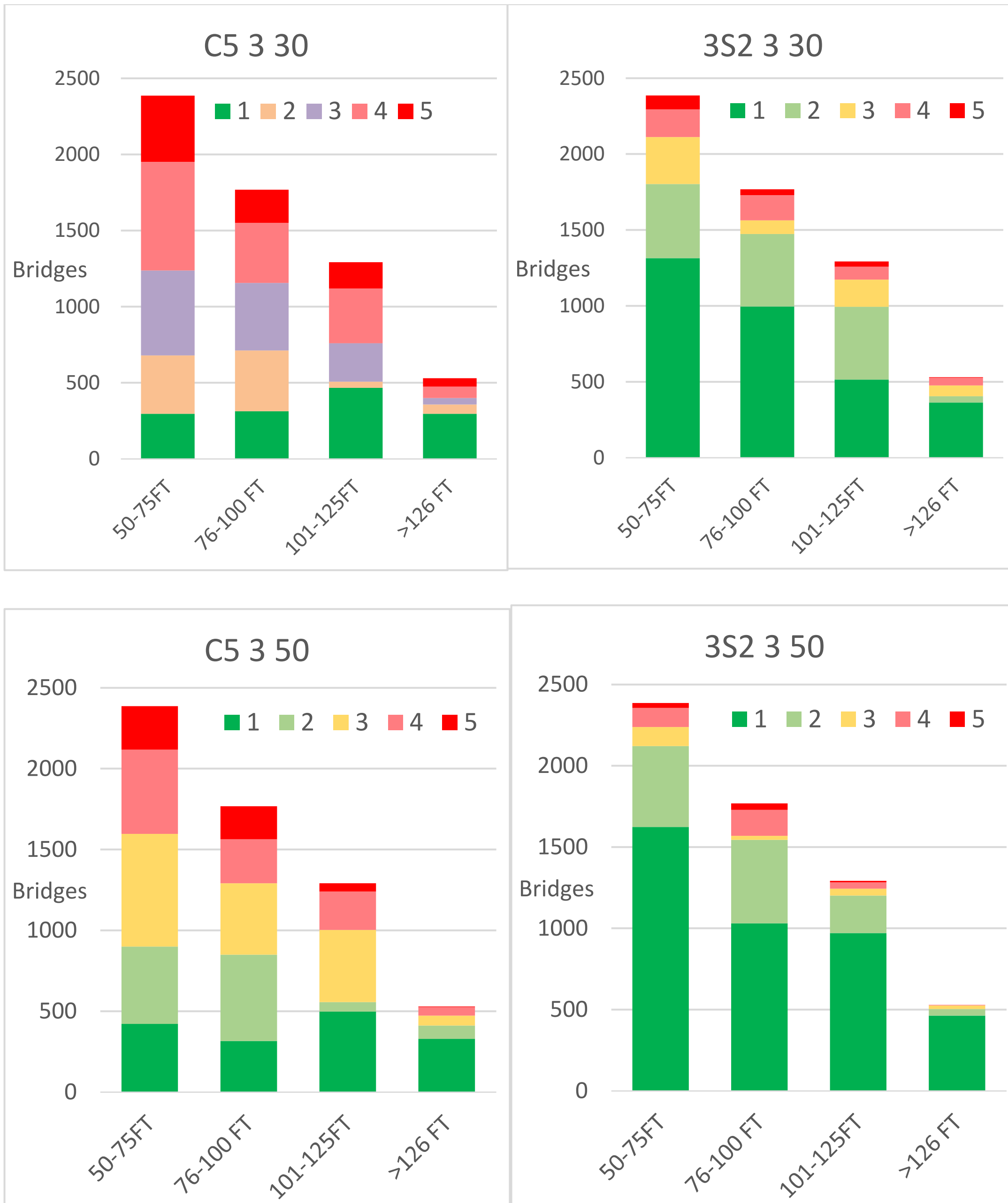

Figure 18: Bar charts showing the variation in higher priority bridges for 3S2 and C5 for 30 ft and 50 ft spacings

5.2. Impact Based on Span

Simple span and multi-span conditions has been considered during this study. In order to get a better understanding about the impact of platoons on multi span bridges, a comparative study between single span and two-span bridges was performed. Figure 19 and Figure 20 shows the variation of C5 truck operator ratings for different span lengths. In the figures, SS refers to single span and MS refers to multi-span bridges. Similarly, EOR LFR refers to the equivalent operator rating of the bridge by LRFR method, i.e. the operator rating after making LFR to LRFR conversion.

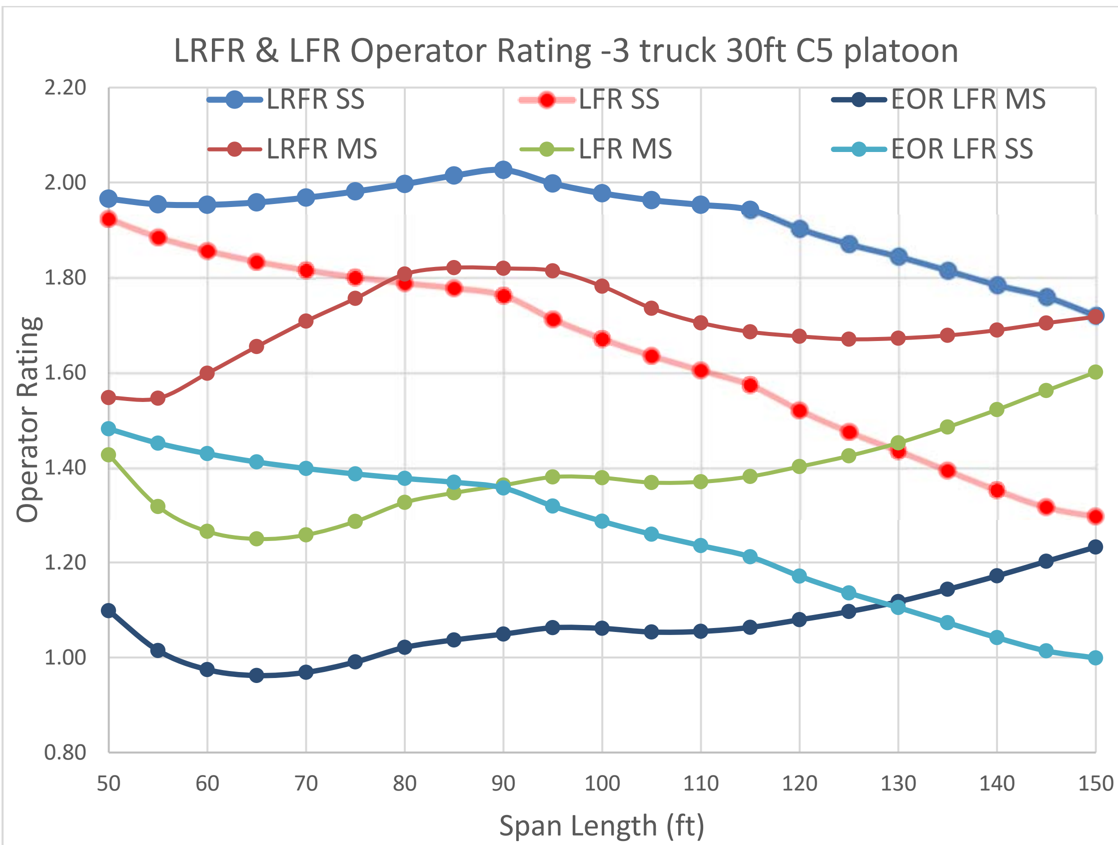

Figure 19 : Comparison of simple span and multi span Operator Rating with span length for 3 C5 truck platoons

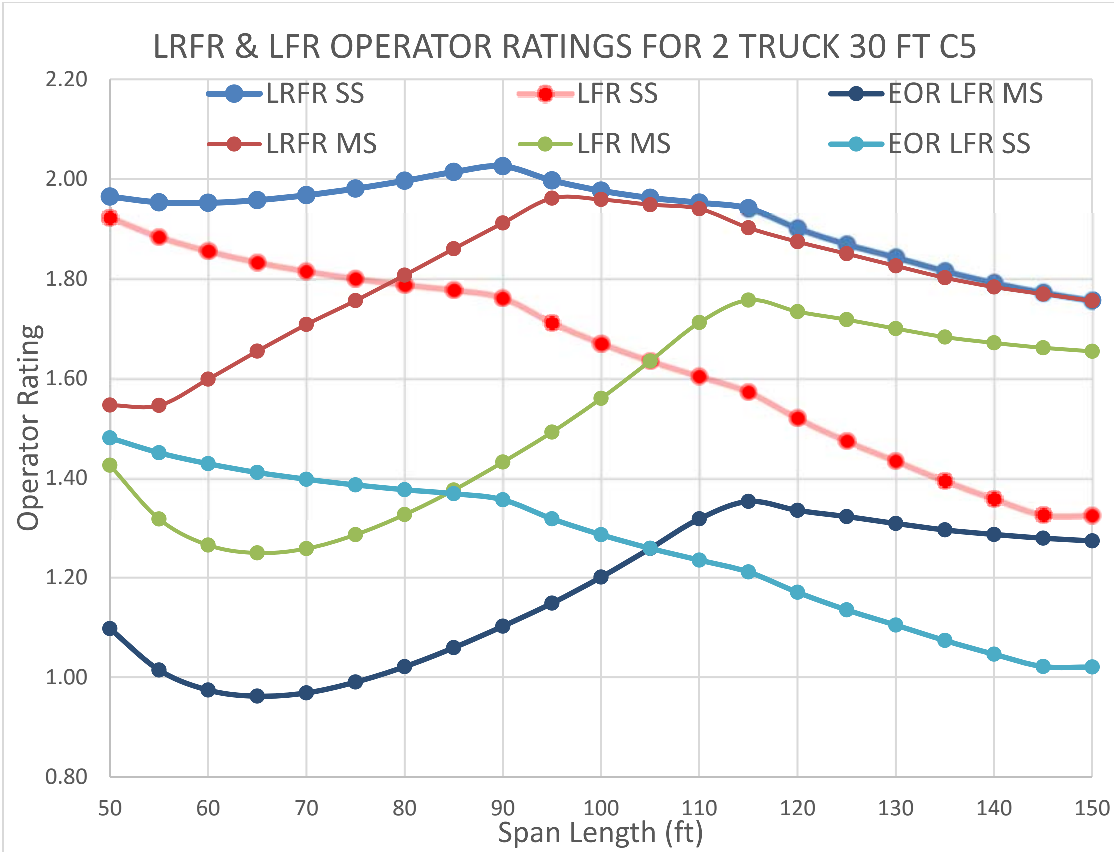

Figure 20 : Comparison of simple span and multi span Operator Rating with span length for 2 C5 truck platoons

It can be seen from the figure that, even though there is a reduction in design moments, for multi-span bridges, there is a significant drop in operator ratings for multi span bridges when compared to simple span bridges. This is mainly due to the fact that, when platoons are considered, more than two bridges are present in the span of the bridge at any given time, hence producing much higher negative moments than that is generated due to the combined design truck and lane loading. The operator ratings for multi-span sections shows a decreasing trend over span lengths of 150 feet, mainly due to the fact that, the effective bridge length exceeds the platoon length significantly, and since lane loading is not considered, the platoon moment effect increase gets reduced.

5.3. Impact Based on Truck Type

Figure 21 show the variation in number of STRAHNET bridges when the truck type changes for different platoon spacings for 3 truck platoon's configurations. The specific trucks with their axle spacing and weights were provided earlier in Figure 4 Type 3S2, ALDOT and DELDOT type trucks have the same truck axle configuration with different wheel loadings. Type 3S2 has the least percentage of high priority bridges as 3S2 has the least GVW among those considered. This indicates that, the impact of truck type on platoons is related to the truck GVW. The higher the GVW, larger the percentage of high priority bridges. Whereas even though ALDOT and DELDOT type trucks have the same GVW (80 kip) and axle configuration, the percentage of high priority bridges is significantly higher for DELDOT trucks. This can be the attributed to the difference in load distribution among the axles. The highest singles axle load in a DELDOT type truck is 20 kip compared to 17.5 kip in ALDOT truck and 15.5 kip in a 3S2 type truck. The comparison of the three truck types conveys that determination of a high priority bridge in a route, depends on the truck axle configuration, GVW and the axle load distribution. Type C5, KENTUCKY and MDOT trucks all have 80-kip GVW, with decreasing distance between the front and rear axles. The percentage of high priority bridges doubles when the axle spacing between the front and rear axles decrease from 17'8'' to 10'. This means that, shorter trucks, carrying very heavy loads are more prone to overload bridges when compared to longer trucks.

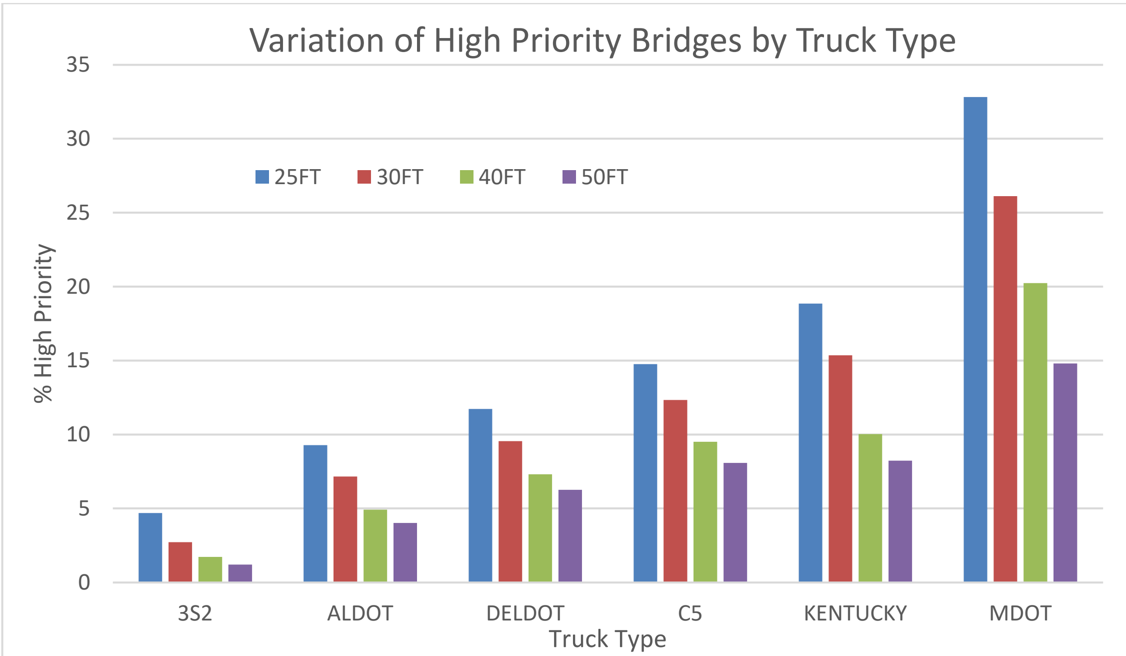

Figure 21: Variation of high priority bridges by truck type and spacing for 2 truck platoons

5.4. Impact Based on Trucks within a Platoon

In order to compare the impact of the number of trucks in a platoon, a comparative study was performed with 2 and 3 trucks. Upon comparison it was observed that the number of high priority bridges increased by less than 15 % when the number of trucks in platoon increased from 2 to 3. Even though the net increase in moment for 3 truck platoons higher for longer span lengths, nearly 80 percentage of the inventory has a span length less than 150 feet, hence minor rise in high priority bridges. Table 7 and Table 8 compare the 3 truck and 2 truck data outputs under different truck spacing for different truck types.

Table 7: 3 truck platoon 30 feet vs 40 feet comparison

Priority Level	3 truck 30 feet spacing			3 truck 40 feet spacing		
	3S2	**ALDOT**	**C5**	**3S2**	**ALDOT**	**C5**
1	3460	2426	1644	4088	2573	1698
2	1487	964	884	1373	1454	1087
3	649	1568	1298	308	1457	1643
4	483	847	1543	366	439	1202
5	169	443	879	113	325	618

Table 8: 2 truck platoon 30 feet vs 40 feet comparison

Priority Level	2 truck 30 feet spacing			2 truck 40 feet spacing		
	3S2	**ALDOT**	**C5**	**3S2**	**ALDOT**	**C5**
1	3620	2565	1693	4119	2655	1793
2	1382	985	999	1375	1403	1058
3	655	1470	1337	292	1451	1612
4	429	852	1407	353	415	1190
5	162	376	812	109	324	595

5.5. Steel Versus Prestressed Girder Bridges

A comparison study between prestress and steel type bridges for different truck and spacing configurations was also conducted. For trucks with lesser GVW, the percent of prestressed bridges under the least priority category is less than that for steel bridges. For trucks heavier than C5, the percentage of bridges under least priority falls significantly below steel bridges for prestress bridges. The variation is parabolic for steel bridges, with the highest fall observed between C5 and 3S2 type trucks. No correlation was observed for variation in platoon and spacing configuration.

Table 9: 2 truck platoon steel vs prestress girder comparison

Priority Level	2 truck platoon at 40 feet spacing					
	3S2- Steel	ALDOT-Steel	C5-Steel	3S2 -Prestressed	ALDOT-Prestressed	C5-Prestressed
1	989	723	671	3130	1932	1122
2	440	266	121	935	1137	937
3	28	440	308	264	1011	1304
4	109	38	347	244	377	843
5	9	108	128	100	216	467

The increase in high priority bridges with reduced span length follows a similar pattern in both steel and prestress bridges. The significant variation in prestress low priority bridges with truck type is mainly due to the fact that, a good percentage of the prestress highway bridges were constructed during the Interstate era in late 1950s and were designed mainly to resist HS20 live loading only. Hence, lesser design moment capacity, along with deterioration effects makes prestress bridges highly susceptible for heavier platoon loading combinations. Table 9 and Table 10 shows the comparison between prestress and steel bridges for 3S2, ALDOT and C5 trucks under 2 and 3 truck platoons at 40 spacing.

Table 10: 3 truck platoon steel vs prestress girder comparison

Priority Level	3 truck platoon 40 feet spacing					
	3S2-Steel	ALDOT-Steel	C5-Steel	3S2 -Prestressed	ALDOT-Prestressed	C5-Prestressed
1	960	641	576	3128	1932	1122
2	448	319	152	925	1135	935
3	37	448	350	271	1009	1293
4	119	58	354	247	381	848
5	11	109	143	102	216	475

6. FUEL SAVINGS STUDY

The output files from Stage 4 were exported to ArcGIS for an approximate cost benefit analysis study. The focus was on implementation of truck platoons along particular routes as well as Texas as a whole. The detailed ArcGIS analysis procedure is mentioned in the following section.

At first TxDOT Roadway Inventory 2016 GIS map containing 640,000 data entries was downloaded from the TxDOT website. The map contains the data of all road segments in Texas. Each road segment has 152 column attributes, corresponding to various structural and traffic conditions. A definition query SEC_STR =1 OR SEC_STR_CON =1 was applied to filter out the STRAHNET highways of Texas. The application of filter reduces the number of data entries to 11300, representing a total distance of 6200 miles.

The TxDOT bridge file containing 55,000 entries was downloaded and added to ArcMap file. The file contains details regarding maximum span, year constructed and the structural evaluation rating of the bridges. The definition query STRAHNET_HWY_DSGNAT = 1 was applied to filter out the STRAHNET classification bridges. The data was then exported to Microsoft Excel using the export to xls. tool within the ArcMap Toolboxes.

The output from the earlier MATLAB analysis was saved as an Excel file and was added to the existing bridge data. The data was then imported back to the ArcMap file. The imported Excel file was then converted to a XY data projection with GCS_North_American_1983 coordinate system. The projection was saved as a map layer.

Necessary definition query was applied to obtain the high priority (Level 5) bridges. The Buffer tool was then utilized to fix a buffer distance around each high priority bridge. The buffer zone was the stretch of roadway in which the platoon system should move at a higher spacing between each other to ensure the safety of the bridge. The buffer radius is fixed at one-mile distance upstream and downstream of the bridge. Most bridges in Texas have a length of less than half a mile and the one-mile radius giving a fairly accurate representation (higher buffer length of 1.5 miles will be tried to compare the changes). The dissolve function was then used to accommodate for the overlapping buffers.

Fields were added in the TxDOT Roadway attribute tables to determine the annual fuel consumption and fuel savings per segment of the roadway. An average fuel consumption of 6 miles per gallon was assumed for trucks based on the data obtained from various sources. The attribute data provided with data of section length and number of trucks passing through that roadway section in a day. These values were multiplied to obtain the annual fuel savings. It was assumed that all the trucks going through the road at present truck traffic levels will be in a platoon. The fuel savings were determined based on the various literature studies done in the prior parts of the report. The fuel consumption rate is taken at 6 mpg based on data obtained from U.S. Energy Information Administration (eia.gov). The Erase tool was then used to erase the roadway map layer with respect to the buffer map layer. This action helps in obtaining non overlapping buffer zones. This helps in comparing the effect of bridges. The process can be repeated for different truck spacings, axle configurations and buffer radius.

The obtained total miles driven per day have been converted to equivalent fuel savings by assuming a fuel saving of 9 % for 20 feet truck to truck spacing, 8 % for 25 feet spacing and 6% for 35 ft spacing respectively based on the studies of McAuliffe et al. (2018). Outputs for 1-mile buffer and 1.5-mile buffer are shown in Tables 11 and Table 12 respectively, for Florida C5 trucks and AASHTO type 3S2 trucks.

Table 11: Output obtained from ArcGIS for 1-mile buffer radius

Truck Type	Truck Spacing	Priority Bridges	Total Fuel Saving (million gal)	Fuel Saving Excluding Bridge Buffers (million gal)	Percentage Change
FLORIDA C5	20 ft	2118	209	151	27.9
FLORIDA C5	25 ft	1677	186	142	23.7
FLORIDA C5	35 ft	1259	140	113	19.4
AASHTO 3S2	20 ft	572	209	188	10.2
AASHTO 3S2	25 ft	362	186	172	7.5
AASHTO 3S2	35 ft	246	140	132	5.7

From Table 11 and Table 12, it can be concluded that, even for a buffer of 1 mile there is a significant reduction in fuel savings, when the condition of bridges is taken into account. This is mainly due to the fact that more than half of the bridges along the highways were constructed in the late 1950s, which means they are at least 50 years old and are approaching the end of their usable life. The study is in total consensus with the report by ASCE on the poor condition of road inventory in Texas.

Table 12 : Output obtained from ArcGIS for 1.5-mile buffer radius

Truck Type	Truck Spacing	Priority Bridges	Total Fuel Saving (million gal)	Fuel Saving Excluding Buffers (million gal)	Percentage Change
FLORIDA C5	20 ft	2118	209	124	40.8
FLORIDA C5	25 ft	1677	186	120	35.5
FLORIDA C5	35 ft	1259	140	97	30.7
AASHTO 3S2	20 ft	572	209	174	16.7
AASHTO 3S2	25 ft	362	186	162	12.9
AASHTO 3S2	35 ft	246	140	126	9.7

Florida C5 trucks are representative of heavy-duty short axle trucks, used mainly in the construction industry for the transport of heavier trucks. 3S2 trucks are representative of normal delivery trucks, in which the idea of platoon may be applied. Type 3S2 bridges have a maximum load capacity of 72 kip as compared to 80 kip for Florida C5. Therefore, the number of critical bridges are significantly less. The fuel saving on introducing truck platoons to Texas can be easily above 150 million gallons per year as shown by the study. Given the fact that one gallon of fuel can produce up to 20 pounds of carbon dioxide means that truck platooning can be an effective method to reduce the overall carbon emissions a well as reduce fuel consumption in the immediate future. It is recommended that a spacing of 20 feet or 25 feet should be used to get maximum economy as shown by the study. This justifies the truck spacing’s used in the bridge impacts study earlier in this document.

When the buffer radius is increased from 1 to 1.5 miles, a reduction in fuel savings percentage of nearly 40-50 percentage has been observed. Therefore, an accurate buffer region should be selected based on actual site conditions and length of bridges in case of a very long bridge. A buffer radius range of 0.75-1.25 miles should be sufficient in most cases to increase the spacing between trucks from a gap of 25 feet to a safe gap of around 50 feet between the trucks.

7. OVERALL CONCLUSIONS

This study has prioritized the STRAHNET bridges within the state of Texas for future truck platoon loading. This was achieved through a comprehensive study of the NBI database combined with a substantial literature review. The information was utilized to make assumptions allowing estimated truck platoon load ratings to be calculated for these bridges likely to foresee platoons (6,550 bridges). The prioritization incorporated the bridge condition through the NBI structural evaluation appraisal ratings. The combined information was categorized from low to high priority bridges. As a result, the study was able to provide a high-level ranking of the STRAHNET bridges to allow TxDOT the ability to prioritize the structures that receive the earliest attention. In addition, a framework was presented for other bridge owners to prioritize their bridges potentially subjected to truck platoon loading. Additional general conclusions from the study include:

- Bridges designed using the LRFD method are likely low priority for further evaluation of future truck platoon loading, unless the condition of the structure is poor. This is because HL-93 live loading adequately envelopes the typical truck platoon configurations in simply supported bridges. The only exception is for multi-span steel bridges under MDOT and DELDOT type trucks with spacing less than 30 ft, where platoon negative moments exceed the design HL93 moments.

- Bridges designed using LFD/ASD methods may require further evaluation for future truck platoon loading, particularly for longer spans and/or poor condition.

- More than 90% of the Texas bridges have a maximum span length less than 150 feet, hence three trucks within a platoon typically governs the analysis. More trucks within a platoon would only affect the longer span bridges.

- Platoon configurations can generate higher moments in the case of multi-span bridges when compared to single span bridges. The maximum multi-span moment goes up to 90% of corresponding single span moments, in certain configurations.

- The spacing between trucks within a platoon is the critical parameter in terms of the potential for bridge overload. The higher priority bridges increased by 50% to 75% when the spacing was increased from 25 to 50 feet for all truck types. On an average, the percentage of high priority bridges decreased by 23%, 45% and 56% when the spacing increased from 25 to 30, 40 and 50 feet, respectively.

- The response of a bridge towards a truck platoon depends on the axle configuration and the axle wheel load distribution of the individual trucks. Higher wheel loads and lesser front axle to rear axle spacing generates more platoon moments in turn decreasing the load rating.

- Fuel savings occurring due to truck platooning can be significantly reduced due to the presence of a high priority bridge along a critical corridor. The annual fuel savings is of the order of $200 million for closer platoon configurations under ideal case conditions.

- Future bridge design of conventional steel and prestressed concrete girder bridges using the current AASHTO LRFD specification should be enough for ruck platoons. This assumes the individual five-axle trucks within a platoon have a GVW limit of 80 kips and are spaced at least 30 feet apart.

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APPENDIX A

PLATOON MOMENTS FOR SINGLE SPAN BRIDGES

This Appendix shows the values of platoon moments used in the analysis of bridges. The moment values were determined by Excel analysis and cross checked using CSi SAP 2000 software

1) For 3 truck platoon at 25 feet spacing (all moments in kip-ft)

SPAN (ft)	3S2	ALDOT	DELDOT	C5	KENTUCKY	MDOT
40	324	360	396	408	415	506
45	376	416	456	501	514	606
50	442	494	536	600	614	706
55	530	592	634	699	713	806
60	618	690	733	798	812	906
65	707	788	831	898	912	1005
70	796	887	930	997	1012	1105
75	885	986	1029	1097	1111	1207
80	974	1085	1128	1199	1212	1316
85	1083	1203	1243	1335	1333	1434
90	1212	1346	1383	1473	1475	1578
95	1340	1490	1522	1610	1629	1727
100	1469	1633	1662	1747	1784	1907
105	1598	1777	1802	1891	1939	2095
110	1729	1924	1942	2056	2130	2291
115	1870	2080	2092	2238	2326	2487
120	2011	2236	2254	2426	2522	2688
125	2184	2430	2439	2623	2719	2921
130	2361	2627	2632	2829	2923	3171
135	2539	2824	2829	3051	3167	3430
140	2717	3022	3031	3301	3411	3717
145	2918	3244	3252	3557	3655	4006
150	3137	3487	3502	3819	3911	4306
155	3355	3731	3752	4082	4195	4606

160	3587	3986	4012	4344	4493	4905
165	3818	4243	4272	4618	4793	5205
170	4049	4499	4532	4918	5092	5505
175	4280	4755	4792	5218	5392	5805
180	4511	5011	5053	5518	5692	6105
185	4776	5309	5352	5817	5992	6405
190	5046	5609	5652	6117	6292	6705
195	5315	5908	5951	6417	6592	7005
200	5585	6208	6251	6717	6892	7304
205	5854	6508	6550	7017	7192	7604
210	6124	6807	6850	7317	7492	7904
215	6393	7107	7149	7617	7791	8204
220	6663	7406	7449	7917	8091	8504
225	6932	7706	7748	8217	8391	8804
230	7202	8005	8048	8516	8691	9104
235	7472	8305	8348	8816	8991	9404
240	7741	8604	8647	9116	9291	9704
245	8011	8904	8947	9416	9591	10004
250	8281	9203	9247	9716	9891	10304
255	8550	9503	9547	10016	10190	10604
260	8820	9802	9847	10316	10490	10904
265	9090	10102	10147	10616	10790	11204
270	9360	10402	10447	10915	11090	11504
275	9630	10702	10746	11215	11390	11804
280	9900	11002	11046	11515	11690	12104
285	10170	11302	11346	11815	11990	12404
290	10440	11602	11646	12115	12290	12704
295	10710	11902	11946	12415	12589	13004
300	10979	12201	12246	12715	12889	13304
305	11249	12501	12546	13015	13189	13604
310	11519	12801	12846	13314	13489	13904
315	11789	13101	13145	13614	13789	14204
320	12059	13401	13445	13914	14089	14504
325	12329	13701	13745	14214	14389	14804
330	12599	14001	14045	14514	14689	15104
335	12869	14301	14345	14814	14989	15404
340	13139	14600	14645	15114	15288	15704

345	13409	14900	14945	15414	15588	16004
350	13678	15200	15245	15714	15888	16304
355	13948	15500	15545	16013	16188	16604
360	14218	15800	15844	16313	16488	16904

2) For 3 truck platoon at 50 feet spacing (all moments in kip-ft)

SPAN (ft)	3S2	ALDOT	DELDOT	C5	KENTUCKY	MDOT
40	324	360	396	408	415	506
45	376	416	456	501	514	606
50	442	494	536	600	614	706
55	530	592	634	699	713	806
60	618	690	733	798	812	906
65	707	788	831	898	912	1005
70	796	887	930	997	1012	1105
75	885	986	1029	1097	1111	1205
80	974	1085	1128	1196	1211	1305
85	1063	1184	1228	1296	1310	1405
90	1153	1283	1327	1396	1410	1505
95	1242	1383	1427	1496	1510	1605
100	1332	1482	1526	1595	1610	1705
105	1421	1581	1625	1695	1710	1805
110	1511	1681	1725	1795	1810	1905
115	1601	1780	1825	1895	1910	2005
120	1690	1880	1924	1995	2009	2105
125	1780	1980	2024	2095	2109	2209
130	1875	2085	2126	2218	2224	2325
135	2003	2226	2265	2354	2365	2468
140	2131	2369	2404	2490	2516	2648
145	2259	2511	2542	2627	2670	2829
150	2387	2653	2681	2792	2852	3012
155	2517	2800	2819	2972	3046	3205
160	2661	2960	2986	3153	3239	3399
165	2823	3141	3169	3344	3433	3592
170	2997	3335	3353	3536	3627	3787
175	3172	3530	3542	3728	3822	3983

180	3348	3724	3734	3920	4017	4188
185	3525	3920	3928	4119	4212	4434
190	3701	4116	4121	4327	4433	4717
195	3877	4312	4322	4563	4676	5006
200	4054	4508	4528	4826	4925	5304
205	4271	4748	4759	5088	5195	5604
210	4494	4995	5019	5351	5492	5904
215	4725	5251	5279	5617	5791	6204
220	4956	5506	5539	5917	6091	6504
225	5187	5763	5799	6217	6391	6804
230	5418	6019	6059	6516	6691	7104
235	5672	6305	6348	6816	6991	7404
240	5941	6604	6647	7116	7291	7704
245	6211	6904	6947	7416	7591	8004
250	6481	7203	7247	7716	7891	8304
255	6750	7503	7547	8016	8190	8604
260	7020	7802	7847	8316	8490	8904
265	7290	8102	8147	8616	8790	9204
270	7560	8402	8447	8915	9090	9504
275	7830	8702	8746	9215	9390	9804
280	8100	9002	9046	9515	9690	10104
285	8370	9302	9346	9815	9990	10404
290	8640	9602	9646	10115	10290	10704
295	8910	9902	9946	10415	10589	11004
300	9179	10201	10246	10715	10889	11304
305	9449	10501	10546	11015	11189	11604
310	9719	10801	10846	11314	11489	11904
315	9989	11101	11145	11614	11789	12204
320	10259	11401	11445	11914	12089	12504
325	10529	11701	11745	12214	12389	12804
330	10799	12001	12045	12514	12689	13104
335	11069	12301	12345	12814	12989	13404
340	11339	12600	12645	13114	13288	13704
345	11609	12900	12945	13414	13588	14004
350	11878	13200	13245	13714	13888	14304
355	12148	13500	13545	14013	14188	14604
360	12418	13800	13844	14313	14488	14904

APPENDIX B

MOMENT RATIOS FOR MULTI-SPAN BRIDGES

This Appendix shows the moment ratio used for calculations of multi-span bridges. +VE value corresponds to the moment ratio at midspan region and -VE corresponds to moment value at support regions.

1) Moment ratios for 2 truck platoon at 30 feet spacing for bridges by LRFR method

SPAN (ft)	C5		3S2		DELDOT	
	+VE	-VE	+VE	-VE	+VE	-VE
45	0.73	0.84	0.55	0.67	0.67	0.74
50	0.73	0.92	0.55	0.73	0.67	0.83
55	0.73	0.92	0.56	0.71	0.68	0.81
60	0.73	0.89	0.57	0.70	0.68	0.80
65	0.73	0.86	0.58	0.70	0.68	0.79
70	0.73	0.83	0.58	0.69	0.68	0.78
75	0.73	0.81	0.58	0.68	0.68	0.77
80	0.72	0.79	0.58	0.67	0.68	0.76
85	0.71	0.77	0.58	0.66	0.68	0.75
90	0.72	0.75	0.58	0.65	0.67	0.73
95	0.72	0.73	0.59	0.64	0.68	0.72
100	0.73	0.71	0.60	0.63	0.68	0.70
105	0.73	0.69	0.61	0.61	0.69	0.69
110	0.73	0.67	0.61	0.60	0.70	0.67
115	0.75	0.65	0.62	0.59	0.70	0.66
120	0.76	0.63	0.63	0.57	0.71	0.64
125	0.77	0.62	0.64	0.56	0.72	0.63
130	0.78	0.60	0.65	0.55	0.73	0.61
135	0.79	0.59	0.66	0.53	0.74	0.60
140	0.80	0.57	0.67	0.52	0.75	0.58
145	0.81	0.55	0.67	0.51	0.76	0.57
150	0.81	0.55	0.68	0.50	0.77	0.56
155	0.82	0.55	0.69	0.48	0.78	0.54

160	0.82	0.56	0.70	0.48	0.78	0.53
165	0.82	0.56	0.70	0.48	0.78	0.54
170	0.83	0.57	0.70	0.49	0.79	0.54
175	0.83	0.57	0.71	0.49	0.79	0.55

1) Moment ratios for 2 truck platoon at 40 feet spacing for bridges by LFR method

SPAN (ft)	**C5**		**3S2**		**DELDOT**	
	+VE	**-VE**	**+VE**	**-VE**	**+VE**	**-VE**
45	0.93	0.96	0.70	0.88	0.86	0.98
50	0.95	1.10	0.71	0.89	0.87	0.99
55	0.97	1.20	0.74	0.96	0.89	1.08
60	0.98	1.31	0.76	1.01	0.91	1.15
65	0.99	1.38	0.78	1.09	0.93	1.24
70	1.01	1.41	0.80	1.14	0.94	1.29
75	1.01	1.40	0.81	1.17	0.95	1.32
80	1.01	1.39	0.82	1.17	0.96	1.32
85	1.00	1.36	0.82	1.16	0.95	1.30
90	1.00	1.32	0.82	1.14	0.95	1.28
95	0.99	1.28	0.81	1.11	0.94	1.25
100	0.98	1.23	0.81	1.08	0.93	1.21
105	0.97	1.18	0.81	1.04	0.92	1.17
110	0.97	1.14	0.80	1.01	0.92	1.13
115	0.97	1.09	0.81	0.97	0.92	1.09
120	0.97	1.04	0.82	0.94	0.93	1.05
125	0.97	1.00	0.82	0.90	0.93	1.01
130	0.98	0.96	0.82	0.87	0.93	0.97
135	0.99	0.92	0.82	0.83	0.93	0.93
140	1.00	0.88	0.83	0.80	0.94	0.90
145	1.00	0.85	0.84	0.77	0.95	0.86
150	1.01	0.81	0.85	0.74	0.96	0.83
155	1.02	0.78	0.85	0.71	0.96	0.80
160	1.02	0.75	0.86	0.68	0.97	0.77
165	1.03	0.72	0.87	0.66	0.98	0.74
170	1.03	0.69	0.87	0.63	0.98	0.71
175	1.03	0.68	0.88	0.61	0.98	0.68

APPENDIX C

MATLAB CODE

This appendix gives the MATLAB program code used for the easy analysis of bridges for platoon moments. The code is-

```
clc;
clear all;
% READ THE DESIGN MOMENTS, PLATOON MOMENTS FROM EXTERNAL EXCEL
FILE
% DEFINE OUTPUT TABLE, TABLE HEADINGS
output= table('size',[6551,20],'VariableTypes',
{'string','string','double','double','double','double','double','double','double','double','string','string','
string','string','double','double','do
uble','string','string','string'});
output.Properties.VariableNames= {'Bridge_id' 'method' 'span' 'design_moment'
'platoon_moment' 'operator_rating'
'Effective_LRFR_Rating' 'NET_RATING' 'latitude' 'longitude' 'bridge_type' 'PRIORITY_INDEX'
'No_of_Spans' 'REMARKS' '
rating_2023' 'rating_2028' 'rating_2033' 'priority_2023' 'priority_2028' 'priority_2033'};
% START OF ITERATION FOR EACH BRIDGE
for i=1:6550
% STORE BRIDGE ID
output{i,1}=bridge{i,1};
% STORE BRIDGE SPAN
output{i,3}=bridge{i,7};
% STORE LATITUDE AND LONGITUDE
output{i,9}=bridge{i,11};
output{i,10}=bridge{i,12};
output{i,13}=bridge{i,43};
span=bridge{i,7};
```

```
% CHECK FOR MULTI SPAN BRIDGES
if str2double(bridge{i,43})>1.1
if bridge{i,5}>2003
% MULTI SPAN LRFR
output{i,2}="LRFR";
for j=1:90
if str2double(multi{j,1})==span
ratio(i)= multi{j,5};
output{i,4}= str2double(multi{j,13});
output{i,5}=str2double(multi{j,13})*str2double(ratio(i));
end
end
% DETERMINE OPERATOR RATING
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<40
output{i,6}=round(1.75*1.35*output{i,4}/1.35/output{i,5},2);
else
output{i,6}=round(1.75*1.10*output{i,4}/1.35/output{i,5},2);
end
output{i,7}=round(output{i,6},2);
end
% MULTISPAN LFR
if bridge{i,5}<2004
output{i,2}="LFR";
if span <176
% LFR MULTISPAN SPAN TRIM
for j=1:85
if str2double(multi{j,1})==span
ratio(i)= multi{j,10};
output{i,4}= str2double(multi{j,17});
output{i,5}=str2double(multi{j,17})*str2double(ratio(i));
end
end
```

```
% DETERMINE OPERATOR RATING
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<40
output{i,6}=round(2.17*1.35*output{i,4}/1.3/output{i,5},2);
else
output{i,6}=round(2.17*1.10*output{i,4}/1.30/output{i,5},2);
end
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<40
output{i,7}= round(0.495*output{i,6},2);
else
output{i,7}= round(0.77*output{i,6},2);
end end end
else
% START OF SINGLE SPAN
if bridge{i,5}>2004
% CONDITION FOR LRFR RATING
output{i,2}="LRFR";
for j=1:93
if moment{j,1}==bridge{i,7}
% DETERMINE DESIGN AND PLATOON MOMENT FOR THE GIVEN SPAN
output{i,4}=round(moment{j,2});
output{i,5}=round(moment{j,4});
end end
% DETERMINE OPERATOR RATING
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<40
output{i,6}=round(1.75*1.35*output{i,4}/1.35/output{i,5},2);
else
output{i,6}=round(1.75*1.10*output{i,4}/1.10/output{i,5},2);
end
output{i,7}=round(output{i,6},2);
end
% CHECK FOR LFR RATING
if bridge{i,5}<2005
```

```
output{i,2}="LFR";
for j=1:93
if moment{j,1}==bridge{i,7}
output{i,4}=round(moment{j,3});
output{i,5}=round(moment{j,4});
end
end
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<40
output{i,6}=round(2.17*1.35*output{i,4}/1.3/output{i,5},2);
output{i,7}=round(0.495*output{i,6},2);
else
output{i,6}=round(2.17*1.1*output{i,4}/1.3/output{i,5},2);
output{i,7}=round(0.77*output{i,6},2);
end end
% CHECK FOR ASR RATING
if bridge{i,5}<1974
output{i,2}="ASR";
for j=1:93
if moment{j,1}==bridge{i,7};
output{i,4}=round(moment{j,3});
output{i,5}=round(moment{j,4});
end end
% DETERMINING CAPACITY OF THE SECTION
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<30
dead= (0.6967-0.007620*span+0.0002554*span*span)*0.8*output{i,4};
capacity= dead+0.5*1.35*output{i,4}*(1+(50/(span+125)));
elseif str2double(bridge{i,8})>=30 && str2double(bridge{i,8})<40
dead=(-0.05*span*span+17.476*span+140)*span*span*0.0001302 ;
capacity = dead+0.5*1.35*output{i,4}*(1+(50/(span+125)));
else
dead=0.0132*1.25*span*output{i,4};
capacity = dead+0.5*1.1*output{i,4}*(1+(50/(span+125)));
```

```
end
% DETERMINING OPERATOR RATING
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<40
output{i,6}=round(((0.75/0.55)*capacity-dead)*2/output{i,5}/(1+(50/(span+125))),2);
output{i,7}=round(0.470*output{i,6},2);
else
output{i,6}=round(((0.75/0.55)*capacity-dead)*2/output{i,5}/(1+(50/(span+125))),2);
output{i,7}=round(0.881*output{i,6},2);
end end end
if str2double(bridge{i,10})>7
output{i,8}=round(output{i,7},2);
end
if str2double(bridge{i,10})==7
output{i,8}=round(0.85*output{i,7},2);
end
if str2double(bridge{i,10})==6
output{i,8}=round(0.75*output{i,7},2);
end
if str2double(bridge{i,10})==5
output{i,8}=round(0.6*output{i,7},2);
end
if str2double(bridge{i,10})<5
output{i,8}=round(0.5*output{i,7},2);
end
% DETERMINE PRIORITY INDEX
if output{i,8}<=0.7
output{i,12}= '5';
elseif output{i,8}<=0.80&& output{i,8}>0.70
output{i,12}= '4';
elseif output{i,8}<=0.90&& output{i,8}>0.80
output{i,12}= '3';
elseif output{i,8}<=1.00&& output{i,8}>0.9
```

```
output{i,12}= '2';
else output{i,8}>1.0
output{i,12}= '1';
end
% DETERMINE TYPE OF BRIDGE
if str2double(bridge{i,8})>20 && str2double(bridge{i,8})<30
output{i,11}="concrete bridge";
elseif str2double(bridge{i,8})>30 && str2double(bridge{i,8})<35
output{i,11}= "prestress concrete girder";
elseif str2double(bridge{i,8})>34 && str2double(bridge{i,8})<40
output{i,11}= "prestress concrete special";
output{i,15}= 0; output{i,16}= 0;output{i,17}= 0;
output{i,20}= '0';output{i,18}= '0';output{i,19}= '0';
output{i,12}= 0;
output{i,12}= 0;
output{i,14}="Not Applicable";
elseif str2double(bridge{i,8})==30
output{i,11}= "prestress concrete segmental";
output{i,15}= 0; output{i,16}= 0;output{i,17}= 0;
output{i,20}= '0';output{i,18}= '0';output{i,19}= '0';
output{i,8}= 0;
output{i,12}= 0;
output{i,14}="Not Applicable";
elseif str2double(bridge{i,8})>40
output{i,11}= "special bridge";
output{i,15}= 0; output{i,16}= 0;output{i,17}= 0;
output{i,20}= '0';output{i,18}= '0';output{i,19}= '0';
output{i,8}= 0;
output{i,12}= 0;
output{i,14}="Not Applicable";
elseif str2double(bridge{i,8})<9
output{i,11}= "steel weathered girder";
```

```
elseif str2double(bridge{i,8})>10 && str2double(bridge{i,8})<19
output{i,11}= "steel girder";
else
output{i,11}= "steel special";
output{i,15}= 0; output{i,16}= 0;output{i,17}= 0;
output{i,20}= '0';output{i,18}= '0';output{i,19}= '0';
output{i,12}= 0;
output{i,8}= 0;
output{i,14}="Not Applicable";
end
if str2double(bridge{i,43})>1.1
if span >176
output{i,11}= "Multi Span Long";
output{i,15}= 1; output{i,16}= 1;output{i,17}= 1;
output{i,20}= '1';output{i,18}= '1';output{i,19}= '1';
output{i,8}= 1;
output{i,12}= 1;
output{i,14}="Special Category";
end end
end
% PRINT OUTPUT TABLE TO EXCEL- update the file directory
writetable (output,'C:\MATLAB\output.csv');
```

APPENDIX D

LRFR LOAD RATING OF STANDARD STEEL GIRDERS

SPAN	Section	Weight (lbs)	DL Mome nt Steel	DL Mome nt Slab	Total DL	Capacity (kipft)	LLF	LL Moment	IR	OR
60	W21 x 1 66	38800	73	377	450	2653	0.73	1093	**1.11**	1.44
60	W24 x 1 31	33750	63	377	440	2451	0.73	1093	**1.01**	1.31
60	W27 x 1 46	35530	67	377	444	2951	0.73	1093	**1.27**	1.65
60	W30 x 1 73	44430	83	377	460	3691	0.73	1093	**1.66**	2.15
60	W33 x 11 8	33560	63	377	440	2989	0.73	1093	**1.30**	1.68
60	W36 x 1 35	35850	67	377	444	3562	0.73	1093	**1.60**	2.08
60	W40 x 1 49	38250	72	377	449	4090	0.73	1093	**1.88**	2.44
65	W24 x 1 62	47010	95	443	538	2904	0.72	1262	**1.04**	1.35
65	W27 x 1 46	42910	87	443	530	2951	0.72	1262	**1.07**	1.38
65	W30 x 1 73	50000	102	443	544	3691	0.72	1262	**1.41**	1.82
65	W33 x 1 30	39640	81	443	523	3229	0.72	1262	**1.20**	1.56
65	W36 x 1 35	40980	83	443	526	3562	0.72	1262	**1.36**	1.76
65	W40 x 1 49	44760	91	443	534	4090	0.72	1262	**1.60**	2.08
70	W24 x 207	62830	137	513	651	3439	0.71	1376	**1.14**	1.47
70	W27 x 1 78	54800	120	513	633	3460	0.71	1376	**1.15**	1.50
70	W30 x 1 73	53510	117	513	630	3691	0.71	1376	**1.26**	1.63
70	W33 x 1 41	45440	99	513	613	3447	0.71	1376	**1.16**	1.50
70	W36 x 1 35	43720	96	513	609	3562	0.71	1376	**1.21**	1.57
70	W40 x 1 49	47790	105	513	618	4090	0.71	1376	**1.44**	1.87
75	W27 x 21 7	70050	164	589	753	4094	0.70	1524	**1.25**	1.62
75	W30 x 1 91	62390	146	589	736	4022	0.70	1524	**1.23**	1.59
75	W33 x 1 69	56580	133	589	722	4005	0.70	1524	**1.23**	1.59
75	W36 x 1 60	53940	126	589	716	4086	0.70	1524	**1.26**	1.64
75	W40 x 1 49	50820	119	589	708	4022	0.70	1524	**1.24**	1.61
80	W27 x 235	81170	203	670	873	4420	0.69	1676	**1.21**	1.57
80	W30 x 1 91	67190	168	670	838	4022	0.69	1676	**1.08**	1.40
80	W33 x 201	71440	179	670	849	4568	0.69	1676	**1.28**	1.65
80	W36 x 1 70	61610	154	670	825	4315	0.69	1676	**1.19**	1.55
80	W40 x 1 67	60790	152	670	822	4539	0.69	1676	**1.28**	1.66

85	W30 x 235	85870	228	757	985	4828	0.69	1831	**1.21**	1.57
85	W33 x 221	82270	219	757	975	4986	0.69	1831	**1.27**	1.64
85	W36 x 1 94	73170	194	757	951	4837	0.69	1831	**1.23**	1.59
85	W40 x 1 83	69580	185	757	942	4886	0.69	1831	**1.25**	1.62
90	W30 x 261	99940	281	849	1130	5313	0.68	1991	**1.22**	1.58
90	W33 x 241	93910	264	849	1113	5230	0.68	1991	**1.20**	1.55
90	W36 x 231	90360	254	849	1103	5555	0.68	1991	**1.30**	1.69
90	W40 x 1 99	79020	222	849	1071	5168	0.68	1991	**1.19**	1.55
95	W33 x 291	117630	349	945	1295	5795	0.67	2155	**1.21**	1.57
95	W36 x 231	94950	282	945	1227	5555	0.67	2155	**1.17**	1.51
95	W40 x 21 5	69043	205	945	1150	5562	0.67	2155	**1.20**	1.56
100	W36 x 247	105980	331	1048	1379	5884	0.67	2323	**1.13**	1.46
100	W40 x 249	107000	334	1048	1382	6366	0.67	2323	**1.26**	1.64
105	W36 x 282	126780	416	1155	1571	6667	0.66	2495	**1.20**	1.55
105	W40 x 277	124950	410	1155	1565	7008	0.66	2495	**1.29**	1.67
110	W40 x 277	130540	449	1268	1716	7008	0.66	2670	**1.17**	1.51
115	W40 x 297	145290	522	1385	1908	7456	0.65	2850	**1.15**	1.49
120	W40 x 324	164190	616	1509	2124	8130	0.65	3034	**1.17**	1.52
								Mean	**1.22**	
								St. Dev.	**0.05**	
								80 percentile	**1.15**	

APPENDIX E

LRFR LOAD RATING ANALYSIS PRESTRESS GIRDERS

Spacing	span	girder	LL factor	DL mom	LL mom	strands	dia	e	d	D	fc	beta	Aps	fps	Mn	IR	OR
6.67	65	Tx46	0.65	794.3	1232	12	0.6	17.6	52.0	43.5	5.0	0.8	3.4	254.8	3653	1.37	1.78
6.67	70	Tx46	0.64	921.2	1376	14	0.6	17.6	52.0	43.5	5.0	0.8	4.0	252.4	4205	1.43	1.86
6.67	75	Tx46	0.62	1057.5	1524	16	0.6	17.4	51.8	43.3	5.0	0.8	4.5	250.0	4718	1.48	1.92
6.67	80	Tx46	0.61	1203.3	1675	18	0.6	17.2	51.6	43.1	5.4	0.8	5.1	248.6	5253	1.51	1.96
6.67	85	Tx46	0.6	1358.4	1831	24	0.6	13.6	48.0	39.5	5.0	0.8	6.8	239.0	6160	1.68	2.18
6.67	90	Tx46	0.59	1522.9	1991	26	0.6	13.8	48.2	39.7	5.2	0.8	7.4	237.6	6644	1.66	2.16
6.67	95	Tx46	0.59	1696.8	2154	28	0.6	13.9	48.3	39.8	6.0	0.8	7.9	238.2	7218	1.65	2.14
6.67	100	Tx46	0.58	1880.1	2322	32	0.6	14.0	48.4	39.9	6.4	0.7	9.1	235.4	8146	1.77	2.30
6.67	90	TX54	0.61	1584.6	1991	18	0.6	20.6	59.6	51.1	9.4	0.6	5.1	255.3	6338	1.47	1.91
6.67	95	TX54	0.6	1765.6	2154	20	0.6	20.4	59.4	50.9	10.4	0.5	5.7	253.9	6986	1.51	1.96
6.67	100	TX54	0.6	1956.3	2322	28	0.6	16.7	55.7	47.2	11.4	0.5	7.9	246.5	8854	1.90	2.46
6.67	105	TX54	0.59	2156.9	2494	30	0.6	16.9	55.9	47.4	12.4	0.4	8.5	244.5	9439	1.89	2.45
6.67	110	TX54	0.58	2367.2	2670	32	0.6	16.9	55.9	47.4	13.4	0.4	9.1	241.8	9965	1.86	2.41
ACTUAL BRIDGE STUDY																	
BRIDGE ID		2184031407232															
6.96	100	TX54	0.71	1987.7	2322	42	0.5	19.0	56.5	48.0	5.0	0.8	8.3	238.1	8758	1.57	2.04
6.96	100	TX54	0.71	1987.7	2322	44	0.5	18.8	56.3	47.8	5.0	0.8	8.6	236.7	9069	1.65	2.14
6.96	100	TX54	0.71	1987.7	2322	50	0.5	18.4	55.8	47.3	5.1	0.8	9.8	233.0	9998	1.89	2.45
8.13	100	TX54	0.691	2135.9	2322	48	0.5	18.5	57.1	48.6	5.1	0.8	9.4	234.9	9941	1.88	2.43
8.33	100	TX54	0.68	2162.5	2322	48	0.5	18.5	57.3	48.8	5.0	0.8	9.4	234.6	9955	1.90	2.46

APPENDIX F

EXAMPLE LOAD RATING ANALYSIS CALCULATION

Example 1- LRFR Prestress Bridge

INPUTS		Units
Bridge ID	**10920004703424**	
Max Span Length	100	ft
Year Built/Rebuilt	2005	
Method of Design	LRFR	
Type of Bridge	Prestress Concrete	
Span Type	Simply Supported	
Truck Type	C5	
Spacing	30	ft
No: of Trucks	3	
Structural Evaluation Rating	7	

CALCULATION			Note:
Assumed I.R. by Bridge Type	1.35		From Table 2
Υ_{IR}	1.75		From AASHTO
Υ_{OR}	1.35		From AASHTO
Design Live Load Moment (L_{Design})	2322	kip-ft	SAP 2000 Analysis
Design Capacity Minus DL Moment (C-DL)	5486	kip-ft	L_{Design}*I.R.*Υ_{IR}
Platoon Moment ($L_{Platoon}$)	1675	kip-ft	SAP 2000 Analysis
Operator Rating for Platoon (OR)	2.43		(C-DL)/ (L Platoon *Υ OR)
LRFR Conversion Factor (C1)	1		From Table 3
Evaluation Rating Conversion Factor (C2)	0.85		From Table 5
Effective Operator Rating (E.O.R.)	2.07		OR*C1*C2
Priority Index	1		By Table 6

Example 2- LFR Steel Bridge

INPUTS		Units
Bridge ID	**22200000813416**	
Max Span Length	155	ft
Year Built/Rebuilt	2001	
Method of Design	LFR	
Type of Bridge	Steel Girder	
Span Type	Simply Supported	
Truck Type	C5	
Spacing	30	ft
No:of Trucks	3	
Structural Evaluation Rating	7	

CALCULATION		Units	Note:
Assumed I.R. by Bridge Type	1.1		From Table 2
Υ_{IR}	2.17		From AASHTO
Υ_{OR}	1.3		From AASHTO
Design Live Load Moment (L_{Design})	2618	kip-ft	SAP 2000 Analysis
Design Capacity Minus DL Moment (C-DL)	6249	kip-ft	L_{Design}*I.R.*Υ_{IR}
Platoon Moment ($L_{Platoon}$)	3756	kip-ft	SAP 2000 Analysis
Operator Rating for Platoon (OR)	1.28		(C-DL)/(L Platoon *Υ OR)
LRFR Conversion Factor (C1)	0.77		From Table 3
Evaluation Rating Conversion Factor (C2)	0.85		From Table 5
Effective Operator Rating (E.O.R.)	0.84		OR*C1*C2
Priority Index	3		By Table 6

APPENDIX G

EXAMPLE OUTPUT OBTAINED BY VBA ANALYSIS

This Appendix gives output obtained for highway district 2 for 3 truck C5 platoon at 30 ft spacing

Bridge ID	Highway District	Span	Year Built/ Rebuilt	Operator Rating	Priority Rating	Priority Index
21270001403495	2	90	2008	2.49	2.12	1
21820031403132	2	65	1970	2.21	0.88	3
21820031403134	2	95	1970	2.33	0.94	2
21820031403135	2	95	1970	2.33	0.94	2
21840000803274	2	100	1978	2.05	0.86	3
21840000803276	2	75	1978	2.21	0.93	2
21840031401083	2	145	2008	1.7	1.44	1
21840031407064	2	50	1969	2.2	0.77	4
21840031407232	2	100	2017	2.43	2.43	1
22200000812357	2	125	1991	1.81	0.77	4
22200000812464	2	115	2013	2.38	2.02	1
22200000813092	2	75	1988	1.29	0.84	3
22200000813093	2	75	1988	1.29	0.84	3
22200000813100	2	75	1963	1.29	0.59	5
22200000813104	2	65	1963	1.25	0.72	4
22200000813126	2	90	1963	1.36	0.79	4
22200000813343	2	60	1988	2.28	0.85	3
22200000813416	2	155	2001	1.28	0.84	3
22200000813419	2	120	2002	1.87	0.79	4
22200000813421	2	180	1990	0	1	1
22200000813429	2	125	1990	1.81	0.68	5
22200000813430	2	125	1990	1.81	0.68	5
22200000814201	2	75	1973	2.26	0.8	4
22200000814204	2	140	1973	1.52	0.99	2
22200000814205	2	140	1973	1.52	0.99	2
22200000814261	2	75	1977	2.21	0.93	2
22200000814488	2	110	2014	2.4	2.04	1
22200000814490	2	95	2014	2.45	2.08	1
22200000814499	2	130	2013	2.26	1.92	1
22200000814514	2	190	2014	1.85	1.57	1

22200000814521	2	130	2014	2.26	1.36	1
22200000814525	2	100	2014	2.43	2.07	1
22200000815227	2	110	1976	1.97	0.74	4
22200000815228	2	110	1976	1.97	0.83	3
22200000815294	2	120	1982	1.87	0.7	5
22200000815300	2	130	1982	1.76	0.65	5
22200000816251	2	120	1995	1.87	0.56	5
22200001415331	2	80	1970	2.29	0.81	3
22200001415383	2	75	1976	2.21	0.82	3
22200001416189	2	55	1961	1.62	0.48	5
22200001416391	2	85	1981	2.18	0.92	2
22200001416408	2	70	1988	2.23	0.94	2
22200001416457	2	120	2001	1.87	0.79	4
22200001416459	2	95	2001	2.1	0.88	3
22200001416478	2	125	2000	1.48	0.97	2
22200001416539	2	130	2014	2.26	1.92	1
22200001416541	2	95	2014	2.45	2.45	1
22200001416573	2	90	2016	2.49	2.49	1
22200001416593	2	235	2016	1.74	1.74	1
22200001416601	2	120	2016	2.33	2.33	1
22200001416619	2	145	2016	2.16	2.16	1
22200001416628	2	270	2018	Inf	1	1
22200008112077	2	60	1990	2.28	0.85	3
22200008112222	2	80	1997	2.2	0.93	2
22200008112223	2	65	1997	2.25	0.94	2
22200009402067	2	125	1974	1.81	0.68	5
22200009402069	2	80	1974	2.2	0.93	2
22200035303433	2	140	2012	2.19	1.86	1
22200036401411	2	120	2001	1.87	0.79	4
22200036401674	2	100	2014	2.43	2.07	1
22200036401688	2	115	2014	2.38	2.38	1
22200050402470	2	75	2014	2.43	2.43	1
22200050402483	2	115	2014	2.38	2.38	1
22200106801117	2	60	1989	1.55	0.58	5
22200106801126	2	65	1965	2.21	0.88	3
22200106801138	2	85	1975	2.18	0.92	2
22200106801289	2	125	2000	1.81	0.77	4
22200106801293	2	150	2000	1.3	0.85	3
22200106801483	2	120	2000	1.87	0.79	4
22200106801563	2	100	2017	2.43	2.43	1

22200106802037	2	70	1957	1.54	0.46	5
22200106802047	2	95	1957	1.38	0.64	5
22200106802058	2	105	1957	1.37	0.79	4
22200106802271	2	90	1957	2.28	1.51	1
22200106802284	2	50	1997	2.36	0.99	2
22200106802286	2	110	1997	1.97	0.83	3
22200106802288	2	90	1997	2.16	0.91	2
22200106802302	2	90	2000	2.16	0.91	2
22200106802332	2	85	1983	2.18	0.81	3
22200106802376	2	200	1991	0	1	1
22200106802551	2	120	2017	2.33	2.33	1
22200106802554	2	120	2017	2.33	2.33	1
22200106802557	2	70	2017	2.42	2.42	1
22200106802567	2	215	2017	Inf	1	1
22200106802568	2	245	2017	Inf	1	1
22200226602092	2	70	1992	2.23	0.94	2
22200237405232	2	100	1973	2.32	0.82	3
22200237405275	2	65	1974	2.25	0.94	2
22200237405279	2	110	2010	2.4	1.8	1
22200237405289	2	85	1975	2.18	0.81	3
22490001306059	2	55	1981	2.31	0.97	2
22490001306068	2	85	1977	2.18	0.92	2
22490001308053	2	85	1972	2.32	0.82	3
21270001403198	2	75	1988	1.29	0.74	4
21270001403231	2	50	1965	2.2	0.77	4
21270001404276	2	65	1966	2.21	0.88	3
21270001422293	2	65	1966	2.21	0.62	5
21270001422294	2	65	1966	2.21	0.78	4
21270001422297	2	50	1966	2.2	0.77	4
21820031402096	2	85	1971	2.32	0.55	5
21820031402099	2	45	1971	2.23	0.79	4
21820031403145	2	75	1970	2.26	0.9	3
21840000803273	2	100	1978	2.05	0.86	3
21840000803315	2	190	1986	0	1	1
21840031401074	2	80	1970	2.29	0.65	5
21840031401076	2	75	1970	2.26	0.9	3
21840031401080	2	60	1970	2.2	0.77	4
21840031401081	2	80	1970	2.29	0.65	5
21840031407045	2	90	1968	1.36	0.63	5
21840031407047	2	75	1968	2.26	0.8	4

22200000812385	2	65	1995	2.25	0.94	2
22200000812386	2	100	1995	2.05	0.76	4
22200000812392	2	70	1995	2.23	0.94	2
22200000812465	2	115	2014	2.38	2.02	1
22200000813099	2	65	1963	1.25	0.58	5
22200000813120	2	60	1963	2.2	0.77	4
22200000813131	2	50	1963	2.2	0.77	4
22200000813136	2	80	1963	1.33	0.61	5
22200000813264	2	50	1988	1.43	0.83	3
22200000813354	2	85	1990	2.18	0.92	2
22200000813380	2	80	1991	2.2	0.82	3
22200000813436	2	105	1989	2.01	0.74	4
22200000813529	2	145	2018	2.16	2.16	1
22200000813530	2	140	2018	2.19	2.19	1
22200000814203	2	140	1973	1.52	0.99	2
22200000814207	2	70	1973	2.23	0.89	3
22200000814209	2	75	1973	2.26	0.8	4
22200000814260	2	75	1977	2.21	0.93	2
22200000814398	2	105	1997	2.01	0.84	3
22200000814400	2	105	2014	2.41	2.05	1
22200000814491	2	95	2014	2.45	2.08	1
22200000814497	2	125	2012	2.3	2.3	1
22200000814506	2	120	2013	2.33	2.33	1
22200000815219	2	120	1975	1.87	0.7	5
22200000815303	2	115	1982	1.93	0.72	4
22200000816328	2	100	1986	2.05	0.76	4
22200000816469	2	125	2013	2.3	1.95	1
22200000816470	2	100	2011	2.43	2.07	1
22200000816471	2	75	2011	2.43	2.43	1
22200000816472	2	240	2014	Inf	1	1
22200001415384	2	95	1976	2.1	0.88	3
22200001415385	2	80	1996	2.2	0.93	2
22200001416192	2	85	1961	1.35	0.78	4
22200001416453	2	90	1999	2.16	0.91	2
22200001416534	2	85	2012	2.47	2.1	1
22200001416546	2	215	2014	Inf	1	1
22200001416548	2	220	2014	Inf	1	1
22200001416561	2	125	2016	2.3	1.95	1
22200001416564	2	140	2016	2.19	2.19	1
22200001416577	2	110	2016	2.4	2.4	1

22200001416579	2	135	2016	2.23	2.23	1
22200001416589	2	120	2016	2.33	2.33	1
22200001416617	2	100	2016	2.43	2.43	1
22200008112082	2	65	1967	2.21	0.78	4
22200008112084	2	65	1967	2.21	0.78	4
22200036303415	2	130	2018	2.26	2.26	1
22200036401655	2	135	2014	2.23	1.9	1
22200036401670	2	115	2014	2.38	2.38	1
22200036401684	2	115	2014	2.38	2.38	1
22200106801167	2	95	1988	1.38	0.8	4
22200106801276	2	80	1989	2.2	0.93	2
22200106801291	2	165	2000	1.25	0.72	4
22200106801446	2	180	2000	1.22	0.71	4
22200106801484	2	115	2001	1.93	0.82	3
22200106801509	2	125	2014	2.3	1.95	1
22200106801511	2	250	2013	Inf	1	1
22200106801520	2	230	2013	Inf	1	1
22200106801564	2	100	2017	2.43	2.43	1
22200106802039	2	70	1957	1.54	0.57	5
22200106802149	2	70	1961	2.23	0.79	4
22200106802198	2	60	1997	2.28	0.96	2
22200106802283	2	50	1997	2.36	0.99	2
22200106802285	2	110	1997	1.97	0.83	3
22200106802377	2	150	1991	1.6	0.92	2
22200106802378	2	200	1991	0	1	1
22200106802382	2	65	1991	2.25	0.83	3
22200106802488	2	120	2010	2.33	2.33	1
22200106802489	2	120	2011	2.33	1.98	1
22200106802553	2	190	2017	Inf	1	1
22200106802556	2	215	2017	Inf	1	1
22200133001018	2	110	2004	1.97	0.83	3
22200226602088	2	75	1992	2.21	0.93	2
22200226602089	2	75	1992	2.21	0.93	2
22200237405196	2	115	1972	2.32	0.82	3
22200237405269	2	70	1974	2.23	0.94	2
22200237405287	2	115	1975	1.93	0.72	4
22200237405496	2	110	2005	2.4	2.4	1
022200S53350001	2	80	1994	2.2	0.93	2
22490001307064	2	60	1981	2.28	0.85	3
22490001307086	2	95	1986	2.1	0.88	3

22490001308091	2	80	1996	2.2	0.93	2
22490001308092	2	80	1996	2.2	0.93	2
21270001403196	2	70	1963	1.26	0.73	4
21270001404057	2	60	1939	2.09	1.1	1
21270001404059	2	60	1987	1.86	0.86	3
21270001404202	2	55	1963	1.62	0.6	5
21270001404268	2	65	1966	2.21	0.52	5
21270001404280	2	65	1966	2.21	0.78	4
21820031402102	2	75	1971	2.26	0.8	4
21840000803280	2	95	2018	2.45	2.08	1
21840000803316	2	140	1986	1.52	0.7	5
21840031401075	2	75	1970	2.26	0.8	4
21840031407046	2	75	1968	2.26	0.8	4
21840031407048	2	50	1968	2.2	0.88	3
21840031407056	2	65	1969	2.21	0.78	4
21840031407067	2	65	1969	2.21	0.52	5
21840031407224	2	90	2012	2.49	2.49	1
21840031407228	2	120	2014	2.33	2.33	1
22200000812358	2	110	1991	1.97	0.83	3
22200000813117	2	75	1963	1.29	0.59	5
22200000813122	2	65	1963	2.21	0.78	4
22200000813129	2	65	1963	2.21	0.78	4
22200000813134	2	70	1963	2.23	0.79	4
22200000813313	2	80	1963	1.33	0.77	4
22200000813346	2	135	1991	1.49	0.86	3
22200000813424	2	210	1990	0	1	1
22200000814206	2	140	1973	1.52	0.99	2
22200000814285	2	125	1976	1.81	0.68	5
22200000814486	2	100	2013	2.43	2.07	1
22200000814516	2	185	2014	1.87	1.59	1
22200000815296	2	95	1982	2.1	0.78	4
22200000816319	2	120	1986	1.87	0.7	5
22200000816321	2	180	1986	0	1	1
22200000816322	2	180	1986	0	1	1
22200000816327	2	215	1986	0	1	1
22200000816475	2	125	2014	2.3	1.95	1
22200000816478	2	125	2014	2.3	1.72	1
22200001402355	2	80	1992	2.2	0.93	2
22200001402356	2	115	1976	1.93	0.82	3
22200001415330	2	95	1970	1.38	0.8	4

22200001415336	2	95	1970	1.38	0.64	5
22200001416190	2	60	1961	1.55	0.46	5
22200001416392	2	75	1981	2.21	0.82	3
22200001416397	2	85	1982	2.18	0.92	2
22200001416417	2	170	1988	1.59	1.04	1
22200001416438	2	80	1990	2.2	0.93	2
22200001416452	2	275	2001	0	1	1
22200001416532	2	125	2013	2.3	1.95	1
22200001416538	2	130	2014	2.26	1.92	1
22200001416580	2	130	2016	2.26	2.26	1
22200001416596	2	120	2016	2.33	2.33	1
22200001416616	2	100	2016	2.43	2.43	1
22200001416620	2	145	2016	2.16	2.16	1
22200008112076	2	60	1967	2.2	0.77	4
22200008112078	2	65	1967	2.21	0.78	4
22200008112168	2	105	1991	2.01	0.74	4
22200036401415	2	235	2001	0	1	1
22200036401686	2	115	2014	2.38	2.38	1
22200106801120	2	65	1965	2.21	0.78	4
22200106801130	2	60	1965	2.2	0.62	5
22200106801160	2	185	2011	Inf	1	1
22200106801218	2	120	1975	1.87	0.79	4
22200106801274	2	95	1989	1.38	0.9	3
22200106801278	2	120	1988	1.87	0.7	5
22200106801290	2	125	2000	1.81	0.68	5
22200106801324	2	115	2003	1.93	0.82	3
22200106801447	2	230	2000	0	1	1
22200106801454	2	115	2001	1.93	0.72	4
22200106801482	2	120	2000	1.87	0.7	5
22200106801495	2	240	2016	Inf	1	1
22200106801507	2	125	2014	2.3	1.95	1
22200106801521	2	230	2013	Inf	1	1
22200106802062	2	65	1993	1.25	0.82	3
22200106802140	2	80	1976	2.2	0.82	3
22200106802180	2	80	1976	2.2	0.82	3
22200106802200	2	60	1997	2.28	0.96	2
22200106802370	2	85	1997	2.18	0.92	2
22200106802371	2	115	1997	1.93	0.82	3
22200106802486	2	95	2010	2.45	2.45	1
22200106802487	2	120	2010	2.33	2.33	1

22200106802548	2	130	2017	2.26	2.26	1
22200106802555	2	120	2017	2.33	2.33	1
22200226602059	2	110	1991	1.97	0.74	4
22200226602101	2	70	1997	2.23	0.83	3
22200237405270	2	70	1974	2.23	0.94	2
22200237405293	2	190	1975	0	1	1
22200237405297	2	70	1975	2.23	0.94	2
22200237405442	2	110	1993	1.97	0.83	3
22200237405443	2	110	1993	1.97	0.74	4
22200237406424	2	85	1981	2.18	0.92	2
022200GG0247005	2	60	2013	2.4	2.4	1
22490001306058	2	55	1981	2.31	0.97	2
22490001307065	2	60	1981	2.28	0.96	2
21270001403195	2	70	1963	1.26	0.73	4
21270001403232	2	50	1965	2.2	0.77	4
21270001403236	2	60	1965	2.2	0.77	4
21270001403243	2	70	1965	2.23	0.79	4
21270001404201	2	55	1963	1.62	0.6	5
21270025905079	2	130	2003	1.76	0.65	5
21820031402094	2	60	1971	2.2	0.77	4
21840031401079	2	60	1970	2.2	0.77	4
21840031407051	2	65	2011	2.4	1.44	1
21840031407059	2	65	1969	2.21	0.88	3
21840031407065	2	50	1969	2.2	0.88	3
21840031407220	2	110	1968	1.37	0.79	4
21840031407233	2	110	2017	2.4	2.4	1
21840106805515	2	125	2014	2.3	2.3	1
22200000812393	2	100	1995	2.05	0.86	3
22200000813119	2	60	1963	2.2	0.77	4
22200000813133	2	60	1963	2.2	0.77	4
22200000813135	2	75	1963	2.26	0.8	4
22200000813263	2	50	1988	1.43	0.83	3
22200000813341	2	80	1988	2.2	0.82	3
22200000813344	2	85	1988	2.18	0.92	2
22200000813413	2	135	2001	1.71	0.72	4
22200000813423	2	215	1990	0	1	1
22200000813426	2	90	1990	2.16	0.64	5
22200000814187	2	90	1981	2.16	0.8	4
22200000814234	2	80	1976	2.2	0.93	2
22200000814238	2	110	1976	1.97	0.74	4

22200000814240	2	120	1976	1.87	0.79	4
22200000814242	2	80	1976	2.2	0.93	2
22200000814262	2	105	1977	2.01	0.74	4
22200000814442	2	115	2005	1.69	1.44	1
22200000814443	2	115	2005	1.69	1.44	1
22200000814501	2	115	2013	2.38	2.02	1
22200000814504	2	110	2014	2.4	2.04	1
22200000814505	2	110	2013	2.4	2.4	1
22200000815211	2	105	1975	2.01	0.74	4
22200000815225	2	85	1976	2.18	0.92	2
22200000816243	2	195	1981	0	1	1
22200000816246	2	95	1981	2.1	0.88	3
22200000816306	2	90	1982	2.16	0.91	2
22200000816312	2	95	1986	2.1	0.78	4
22200000816325	2	95	1985	2.1	0.88	3
22200000816329	2	110	1986	1.97	0.74	4
22200001402439	2	115	2007	2.38	2.02	1
22200001415338	2	85	1970	2.32	0.93	2
22200001416339	2	65	2008	2.4	1.8	1
22200001416480	2	120	2000	1.87	0.79	4
22200001416545	2	220	2014	1.76	1.76	1
22200001416562	2	140	2016	2.19	2.19	1
22200001416563	2	145	2016	2.16	2.16	1
22200001416565	2	120	2016	2.33	2.33	1
22200001416590	2	115	2016	2.38	2.38	1
22200001416594	2	230	2016	1.75	1.75	1
22200001416599	2	145	2016	2.16	2.16	1
22200001416600	2	145	2016	2.16	2.16	1
22200001416604	2	65	2016	2.4	2.4	1
22200001416621	2	145	2016	2.16	2.16	1
22200008112079	2	65	1967	2.21	0.78	4
22200008112081	2	65	1967	2.21	0.78	4
22200035303434	2	140	2012	2.19	1.86	1
22200036401414	2	175	2001	1.57	1.03	1
22200036401668	2	90	2014	2.49	2.12	1
22200036401675	2	120	2014	2.33	2.33	1
22200036401683	2	100	2014	2.43	1.82	1
22200036405654	2	100	2014	2.43	2.07	1
22200050402469	2	75	2014	2.43	2.43	1
22200050402488	2	250	2013	1.73	1.47	1

22200106801116	2	55	1964	1.62	0.6	5
22200106801139	2	85	1975	2.18	0.92	2
22200106801215	2	125	1975	1.81	0.77	4
22200106801277	2	140	1989	1.52	0.99	2
22200106801294	2	110	2000	1.97	0.59	5
22200106801349	2	80	1988	2.2	0.93	2
22200106801350	2	80	1987	2.2	0.93	2
22200106801448	2	165	2003	1.61	0.93	2
22200106801499	2	120	2014	2.33	2.33	1
22200106801506	2	125	2014	2.3	1.95	1
22200106801512	2	250	2013	Inf	1	1
22200106802107	2	145	1993	1.62	0.6	5
22200106802145	2	80	1962	1.33	0.77	4
22200106802163	2	100	1983	2.05	0.76	4
22200106802173	2	90	1986	2.16	0.91	2
22200106802197	2	60	1997	2.28	0.96	2
22200106802267	2	75	1997	1.58	0.59	5
22200106802307	2	115	2009	2.38	1.79	1
22200106802348	2	110	1988	1.97	0.74	4
22200106802485	2	95	2010	2.45	2.08	1
22200106802552	2	255	2017	Inf	1	1
22200106802559	2	70	2017	2.42	2.42	1
22200106802561	2	70	2017	2.42	2.42	1
22200106802566	2	205	2017	Inf	1	1
22200106802569	2	215	2017	Inf	1	1
22200106802570	2	225	2017	Inf	1	1
22200226602073	2	75	1994	2.21	0.93	2
22200237405276	2	70	1974	2.23	0.83	3
22200237405281	2	110	1993	1.97	0.74	4
22200237405495	2	110	2005	2.4	2.04	1
22200237406422	2	75	1981	2.21	0.82	3
22490001306061	2	70	1981	2.23	0.94	2
22490001308069	2	95	1990	2.1	0.88	3
20730031404117	2	80	1970	2.29	0.81	3
21270001403193	2	60	2007	1.6	0.96	2
21270001403194	2	80	1963	1.33	0.51	5
21270001403197	2	80	1988	1.33	0.77	4
21270001404272	2	65	1966	2.21	0.78	4
21270001422295	2	65	1966	2.21	0.78	4
21270001422298	2	50	1966	2.2	0.77	4

21820031402098	2	45	1971	2.23	0.79	4
21820031402107	2	75	1971	2.26	0.9	3
21820031403146	2	75	1970	2.26	0.9	3
21840031401084	2	80	1970	2.29	0.81	3
21840031407061	2	85	1969	1.35	0.78	4
21840031407230	2	65	2017	2.4	2.4	1
22130025903023	2	80	2008	2.45	2.45	1
22200000812387	2	110	1995	1.97	0.83	3
22200000813101	2	75	1963	1.29	0.59	5
22200000813109	2	60	1963	1.27	0.74	4
22200000813128	2	45	1963	2.41	0.68	5
22200000813347	2	145	1988	1.56	1.02	1
22200000813402	2	150	1998	1.3	0.85	3
22200000813418	2	155	2002	1.63	1.07	1
22200000813438	2	80	1991	2.2	0.82	3
22200000813528	2	140	2018	2.19	2.19	1
22200000813531	2	125	2018	2.3	2.3	1
22200000814183	2	55	1981	2.31	0.97	2
22200000814202	2	75	1973	2.26	0.9	3
22200000814208	2	70	1973	2.23	0.79	4
22200000814210	2	75	1973	2.26	0.9	3
22200000814232	2	80	1976	2.2	0.93	2
22200000814235	2	80	1976	2.2	0.93	2
22200000814241	2	80	1976	2.2	0.93	2
22200000814258	2	95	1977	2.1	0.78	4
22200000814489	2	95	2013	2.45	2.08	1
22200000814502	2	115	2013	2.38	2.38	1
22200000815223	2	95	1976	2.1	0.78	4
22200000815226	2	110	1976	1.97	0.83	3
22200000815255	2	90	1977	2.16	0.8	4
22200000815295	2	120	1982	1.87	0.7	5
22200000816323	2	160	1986	1.62	1.06	1
22200000816324	2	160	1986	1.62	0.94	2
22200000816473	2	125	2014	2.3	1.95	1
22200000816481	2	240	2014	Inf	1	1
22200000816482	2	125	2013	2.3	1.95	1
22200001402496	2	100	2009	2.43	2.07	1
22200001416150	2	80	1999	1.33	0.87	3
22200001416390	2	100	1981	2.05	0.86	3
22200001416431	2	105	1990	2.01	0.84	3

22200001416479	2	120	2000	1.87	0.79	4
22200001416540	2	85	2014	2.47	2.47	1
22200001416543	2	95	2015	2.45	2.08	1
22200001416550	2	95	2015	2.45	2.45	1
22200001416556	2	85	2016	2.47	2.47	1
22200001416574	2	110	2016	2.4	2.4	1
22200001416584	2	135	2016	2.23	2.23	1
22200001416588	2	125	2016	2.3	2.3	1
22200001416592	2	230	2016	1.75	1.75	1
22200001416602	2	120	2016	2.33	2.33	1
22200001416605	2	125	2016	2.3	2.3	1
22200001416609	2	125	2016	2.3	2.3	1
22200001416618	2	120	2015	2.33	1.98	1
22200008112172	2	110	1991	1.97	0.74	4
22200008112209	2	120	2006	2.33	1.75	1
22200009402068	2	115	1974	1.93	0.72	4
22200036401657	2	135	2014	2.23	2.23	1
22200036405653	2	105	2014	2.41	2.05	1
22200106801009	2	90	1985	1.36	0.79	4
22200106801136	2	90	1967	1.36	0.79	4
22200106801166	2	105	1987	2.01	0.84	3
22200106801169	2	140	1988	1.52	0.88	3
22200106801213	2	70	1975	2.23	0.94	2
22200106801216	2	125	1975	1.81	0.68	5
22200106801265	2	60	1965	2.2	0.77	4
22200106801295	2	120	2000	1.87	0.7	5
22200106801326	2	90	2003	2.16	0.91	2
22200106801449	2	200	2001	0	1	1
22200106801498	2	120	2014	2.33	2.33	1
22200106801502	2	125	2013	2.3	1.95	1
22200106801510	2	230	2013	Inf	1	1
22200106802036	2	80	1957	1.63	0.61	5
22200106802287	2	90	1997	2.16	0.91	2
22200106802301	2	90	2003	2.16	0.91	2
22200106802360	2	95	1988	2.1	0.78	4
22200106802372	2	75	1997	2.21	1.09	1
22200106802375	2	220	1991	0	1	1
22200106802415	2	125	1986	1.81	0.77	4
22200133001017	2	125	2004	1.81	0.77	4
22200226602060	2	115	1991	1.93	0.82	3

22200226602093	2	70	1992	2.23	0.94	2
22200237405272	2	110	1974	1.97	0.74	4
22200237405273	2	110	1974	1.97	0.74	4
22200237405277	2	70	1974	2.23	0.94	2
22200237405278	2	110	2010	2.4	1.8	1
22200237405290	2	145	1971	1.56	0.9	3
22200237405314	2	120	1972	2.28	0.8	4
22200237406514	2	125	2011	2.3	1.95	1
22490001306063	2	95	1981	2.1	0.88	3
22490001307067	2	70	1981	2.23	0.94	2
22490001308054	2	85	1972	2.32	0.82	3
22490001308100	2	135	1972	1.49	0.86	3
20730031404118	2	80	1970	2.29	0.92	2
21270001404266	2	60	1966	2.2	0.77	4
21820031403090	2	95	1971	2.33	0.83	3
21820031403130	2	95	1970	2.33	0.55	5
21820031403144	2	100	1970	2.32	0.55	5
21840000803279	2	85	1978	2.18	0.81	3
21840031407040	2	65	2017	2.4	1.44	1
21840031407044	2	60	1968	2.2	0.77	4
21840031407057	2	65	1969	2.21	0.78	4
21840031407222	2	65	2011	2.4	2.04	1
21840031407225	2	100	2011	2.43	2.07	1
21840106805516	2	125	2014	2.3	1.95	1
22200000812395	2	90	1995	2.16	0.91	2
22200000812396	2	110	1991	1.97	0.74	4
22200000813103	2	70	1963	1.26	0.73	4
22200000813106	2	60	1963	1.27	0.74	4
22200000813110	2	60	1963	1.27	0.74	4
22200000813132	2	50	1963	2.2	0.77	4
22200000813165	2	70	1965	1.26	0.73	4
22200000813181	2	65	1969	2.21	0.78	4
22200000813337	2	95	1985	2.1	0.78	4
22200000813342	2	75	1988	2.21	0.93	2
22200000813428	2	90	1990	2.16	0.8	4
22200000813534	2	160	2018	2.02	2.02	1
22200000814233	2	80	1976	2.2	0.93	2
22200000814259	2	95	1977	2.1	0.78	4
22200000814484	2	100	2013	2.43	2.07	1
22200000814485	2	110	2013	2.4	2.04	1

22200000814496	2	125	2013	2.3	2.3	1
22200000814498	2	110	2013	2.4	2.04	1
22200000815254	2	90	1977	2.16	0.91	2
22200000815257	2	125	1977	1.81	0.68	5
22200000816244	2	140	1981	1.66	0.7	5
22200000816286	2	110	1982	1.97	0.74	4
22200000816467	2	125	2013	2.3	1.95	1
22200001402340	2	70	2008	2.42	1.82	1
22200001415333	2	85	1970	2.32	0.65	5
22200001415386	2	85	1996	2.18	0.92	2
22200001416191	2	55	1961	1.62	0.48	5
22200001416412	2	135	1988	1.71	0.72	4
22200001416427	2	105	1990	2.01	0.59	5
22200001416443	2	100	1995	2.05	0.86	3
22200001416464	2	70	2001	2.23	0.94	2
22200001416466	2	120	2001	1.87	0.7	5
22200001416544	2	175	2014	1.64	1.64	1
22200001416547	2	180	2014	Inf	1	1
22200001416566	2	120	2016	2.33	2.33	1
22200001416575	2	120	2016	2.33	2.33	1
22200001416578	2	130	2016	2.26	2.26	1
22200001416587	2	115	2016	2.38	2.38	1
22200001416591	2	85	2016	2.47	2.47	1
22200001416598	2	140	2016	2.19	2.19	1
22200001416606	2	125	2016	2.3	2.3	1
22200001416624	2	125	2016	2.3	2.3	1
22200008112171	2	95	1991	2.1	0.88	3
22200008112195	2	95	1997	2.1	0.78	4
22200008112210	2	120	2006	2.33	1.75	1
22200009402103	2	90	1990	2.16	0.91	2
22200017206051	2	65	1962	1.53	0.57	5
22200035303196	2	110	2004	1.97	0.83	3
22200036401410	2	125	2001	1.81	0.77	4
22200036401659	2	135	2014	2.23	1.9	1
22200050402489	2	235	2013	1.74	1.48	1
22200106801115	2	65	1964	1.53	0.57	5
22200106801125	2	70	1965	2.23	0.79	4
22200106801272	2	95	1989	1.38	0.9	3
22200106801275	2	80	1989	2.2	0.82	3
22200106801445	2	180	2000	1.22	0.71	4

22200106801450	2	225	2001	0	1	1
22200106801455	2	120	2001	1.87	0.79	4
22200106801481	2	125	2000	1.81	0.77	4
22200106801504	2	200	2014	Inf	1	1
22200106801505	2	240	2014	Inf	1	1
22200106802060	2	70	1983	1.26	0.73	4
22200106802154	2	90	1987	1.36	0.89	3
22200106802171	2	105	1987	2.01	0.74	4
22200106802172	2	70	1983	1.26	0.73	4
22200106802192	2	105	1995	2.01	0.84	3
22200106802369	2	115	1997	1.93	0.96	2
22200106802490	2	105	2011	2.41	2.05	1
22200106802491	2	115	2011	2.38	2.02	1
22200106802493	2	70	2011	2.42	2.42	1
22200106802560	2	70	2017	2.42	2.42	1
22200226602058	2	115	1991	1.93	0.82	3
22200237405235	2	120	1973	2.28	0.64	5
22200237405239	2	110	1973	2.32	0.82	3
22200237405284	2	110	1975	1.97	0.83	3
22200237405296	2	70	1975	2.23	0.94	2
22200355902001	2	95	1992	2.1	0.88	3
22490001308052	2	95	1972	2.33	0.83	3
22490001308072	2	105	1995	2.01	0.84	3
22490001308094	2	95	1996	2.1	0.88	3
21270001403016	2	95	2006	2.45	2.08	1
21270001404281	2	60	1987	2.28	0.85	3
21270001902046	2	65	2002	1.25	0.82	3
21820031402095	2	60	1971	2.2	0.77	4
21820031403126	2	80	1970	2.29	0.81	3
21840000803278	2	85	1978	2.18	0.81	3
21840031401071	2	50	1970	2.2	0.88	3
21840031401082	2	145	2008	1.7	1.28	1
21840031407049	2	50	1968	2.2	0.88	3
21840031407058	2	65	1969	2.21	0.88	3
21840031407231	2	100	2017	2.43	2.43	1
21840106805514	2	125	2014	2.3	2.3	1
021840B00422001	2	120	1993	1.87	0.79	4
22200000812356	2	80	1989	1.33	0.77	4
22200000812394	2	90	1995	2.16	0.91	2
22200000813121	2	65	1963	2.21	0.88	3

22200000813125	2	90	1963	1.36	0.63	5
22200000813127	2	45	1963	2.41	0.68	5
22200000813381	2	100	1991	2.05	0.76	4
22200000813417	2	245	2002	0	1	1
22200000813422	2	165	1990	1.61	1.05	1
22200000813441	2	125	2002	1.81	0.77	4
22200000813533	2	140	2018	2.19	2.19	1
22200000813536	2	160	2018	2.02	2.02	1
22200000814236	2	80	1976	2.2	0.93	2
22200000814495	2	125	2013	2.3	2.3	1
22200000814522	2	125	2016	2.3	2.3	1
22200000815297	2	95	1982	2.1	0.62	5
22200000815299	2	130	1982	1.76	0.65	5
22200000816250	2	120	1995	1.87	0.56	5
22200000816307	2	90	1982	2.16	0.91	2
22200000816320	2	120	1986	1.87	0.79	4
22200000816326	2	100	1986	2.05	0.86	3
22200001402354	2	80	1976	2.2	0.93	2
22200001402500	2	100	2009	2.43	2.07	1
22200001415328	2	75	1970	2.26	0.9	3
22200001415334	2	85	1970	2.32	0.82	3
22200001416008	2	75	2007	2.43	2.07	1
22200001416181	2	85	1962	2.32	0.65	5
22200001416393	2	85	1981	2.18	0.81	3
22200001416398	2	75	1982	2.21	0.82	3
22200001416419	2	110	1988	1.97	0.74	4
22200001416425	2	115	1990	1.93	0.82	3
22200001416434	2	80	1990	2.2	0.93	2
22200001416456	2	120	2001	1.87	0.79	4
22200001416458	2	95	2001	2.1	0.88	3
22200001416465	2	70	2001	2.23	0.94	2
22200001416533	2	110	2012	2.4	2.04	1
22200001416535	2	85	2013	2.47	2.1	1
22200001416572	2	140	2016	2.19	2.19	1
22200001416581	2	125	2016	2.3	2.3	1
22200001416586	2	140	2016	2.19	2.19	1
22200001416595	2	125	2016	2.3	2.3	1
22200001416597	2	115	2016	2.38	2.38	1
22200001416603	2	120	2016	2.33	2.33	1
22200001416608	2	105	2016	2.41	2.41	1

22200001416623	2	115	2016	2.38	2.38	1
22200001416629	2	130	2018	2.26	2.26	1
22200009402078	2	125	1979	1.81	0.68	5
22200009402081	2	110	1989	1.97	0.83	3
22200017206192	2	85	1972	2.32	0.82	3
22200035303197	2	110	2004	1.97	0.83	3
22200036401647	2	105	2014	2.41	2.05	1
22200036401661	2	135	2014	2.23	2.23	1
22200036401671	2	115	2014	2.38	2.02	1
22200036401676	2	95	2014	2.45	2.45	1
22200036401681	2	95	2014	2.45	2.08	1
22200106801129	2	70	1965	2.23	0.89	3
22200106801164	2	55	1986	1.32	0.87	3
22200106801212	2	70	1975	2.23	0.94	2
22200106801214	2	125	1975	1.81	0.68	5
22200106801217	2	125	1975	1.81	0.68	5
22200106801327	2	125	2003	1.81	0.77	4
22200106801456	2	130	1999	1.76	0.74	4
22200106801503	2	125	2014	2.3	1.95	1
22200106802061	2	65	1993	1.25	0.72	4
22200106802174	2	70	1972	1.26	0.58	5
22200106802199	2	60	1997	2.28	0.96	2
22200106802345	2	95	1988	2.1	0.88	3
22200106802353	2	75	1997	1.58	0.47	5
22200106802549	2	130	2017	2.26	2.26	1
22200106802550	2	120	2017	2.33	2.33	1
22200237405233	2	100	1973	2.32	0.82	3
22200237405236	2	175	1973	1.57	0.91	2
22200237405237	2	160	1973	1.62	0.94	2
22200237405238	2	110	1973	2.32	0.82	3
22200237405274	2	65	1974	2.25	0.94	2
22200237405288	2	85	1975	2.18	0.81	3
22200237405313	2	70	1972	2.23	0.79	4
22200237405515	2	125	2015	2.3	2.3	1
22200237406423	2	150	1981	1.59	0.67	5
22200355902002	2	100	1992	2.05	0.86	3
22490001306060	2	70	1981	2.23	0.94	2
22490001307066	2	70	1981	2.23	0.94	2
22490001307087	2	95	1986	2.1	0.88	3
22490001308073	2	105	2010	1.74	1.48	1

22490001308330	2	120	2014	2.33	2.33	1
22490001308331	2	120	2014	2.33	2.33	1
21270025905078	2	130	2003	1.76	0.74	4
21820031402101	2	75	1971	2.26	0.8	4
21820031402108	2	75	1971	2.26	0.9	3
21820031403125	2	80	1970	2.29	0.81	3
21820031403131	2	65	1970	2.21	0.78	4
21840000803275	2	75	1978	2.21	0.93	2
21840031401054	2	50	1969	2.2	0.77	4
21840031401055	2	50	1969	2.2	0.77	4
21840031401072	2	50	1970	2.2	0.88	3
21840031407042	2	65	1968	2.21	0.62	5
21840031407043	2	60	1968	2.2	0.77	4
21840031407050	2	90	1988	1.36	0.63	5
21840031407068	2	90	1969	1.36	0.79	4
21840031407223	2	70	2011	2.42	2.06	1
021840AA0511001	2	60	2005	2.4	2.04	1
22200000812252	2	70	1981	2.23	0.83	3
22200000812333	2	100	1986	2.05	0.76	4
22200000812368	2	125	1991	1.81	0.77	4
22200000813097	2	75	1963	1.29	0.59	5
22200000813105	2	60	1963	1.27	0.74	4
22200000813336	2	80	1986	2.2	0.82	3
22200000813355	2	80	1990	2.2	0.82	3
22200000813374	2	110	1991	1.97	0.74	4
22200000813403	2	150	1998	1.3	0.85	3
22200000813420	2	250	2002	0	1	1
22200000813443	2	95	2003	2.1	0.88	3
22200000813527	2	280	2018	Inf	1	1
22200000813535	2	130	2018	2.26	2.26	1
22200000814182	2	55	1981	2.31	0.86	3
22200000814188	2	90	1981	2.16	0.8	4
22200000814199	2	75	1973	2.26	0.8	4
22200000814200	2	75	1973	2.26	0.8	4
22200000814231	2	80	1976	2.2	0.93	2
22200000814239	2	120	1976	1.87	0.79	4
22200000814487	2	115	2014	2.38	2.02	1
22200000814492	2	125	2014	2.3	1.95	1
22200000814500	2	105	2013	2.41	2.05	1
22200000814503	2	110	2013	2.4	2.04	1

22200000814515	2	125	2014	2.3	1.95	1
22200000816002	2	110	2006	2.4	2.04	1
22200000816245	2	95	1981	2.1	0.88	3
22200000816247	2	95	1981	2.1	0.88	3
22200000816289	2	105	1982	2.01	0.74	4
22200000816466	2	115	2013	2.38	2.38	1
22200000816477	2	270	2014	Inf	1	1
22200000816479	2	265	2014	Inf	1	1
22200001402341	2	65	1976	2.25	0.83	3
22200001402343	2	65	1976	2.25	0.94	2
22200001402345	2	80	1976	2.2	0.93	2
22200001402347	2	75	1976	2.21	0.93	2
22200001402352	2	80	1976	2.2	0.93	2
22200001415326	2	100	1970	1.38	0.8	4
22200001415327	2	90	1970	2.35	0.66	5
22200001416151	2	70	1960	1.26	0.58	5
22200001416399	2	105	1982	2.01	0.74	4
22200001416571	2	130	2016	2.26	2.26	1
22200001416610	2	135	2016	2.23	2.23	1
22200001416622	2	140	2016	2.19	2.19	1
22200001416627	2	150	2018	2.11	2.11	1
22200008112083	2	65	1967	2.21	0.78	4
22200017104030	2	75	1968	2.26	0.64	5
22200017206265	2	105	2004	2.01	0.84	3
22200106801113	2	65	2018	1.65	1.4	1
22200106801119	2	65	1965	2.21	0.88	3
22200106801127	2	50	1998	2.36	0.88	3
22200106801133	2	60	1965	1.55	0.58	5
22200106801161	2	160	2011	1.71	1.28	1
22200106801162	2	105	1983	2.01	0.74	4
22200106801190	2	125	1999	1.81	0.68	5
22200106801195	2	60	1965	1.55	0.58	5
22200106801196	2	60	1986	1.55	0.58	5
22200106801292	2	100	2000	2.05	0.86	3
22200106801297	2	120	2000	1.87	0.79	4
22200106801351	2	130	1988	1.76	0.74	4
22200106801451	2	225	2001	0	1	1
22200106801457	2	130	1999	1.76	0.74	4
22200106801500	2	140	2014	2.19	1.86	1
22200106801501	2	140	2013	2.19	1.86	1

22200106801508	2	140	2014	2.19	1.86	1
22200106802057	2	80	1976	1.33	0.77	4
22200106802330	2	125	1983	1.81	0.68	5
22200106802379	2	145	1991	1.56	0.9	3
22200106802492	2	160	2010	2.02	1.72	1
22200106802558	2	90	2017	2.49	2.49	1
22200226602061	2	100	1991	2.05	0.76	4
22200226602072	2	75	1994	2.21	0.93	2
22200237405292	2	185	1975	0	1	1
22200237405446	2	140	1996	1.66	0.7	5
022200ZW3190001	2	80	1980	2.2	0.93	2
22490001306327	2	70	2010	2.42	2.06	1
22490001308093	2	95	1996	2.1	0.88	3